REPORT

OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1953

COMMONWEALTH MYCOLOGICAL INSTITUTE
1 JUN 1954

Rothamsted Experimental Station
Harpenden, Herts.

LAWES AGRICULTURAL TRUST

REPORT

for

1953

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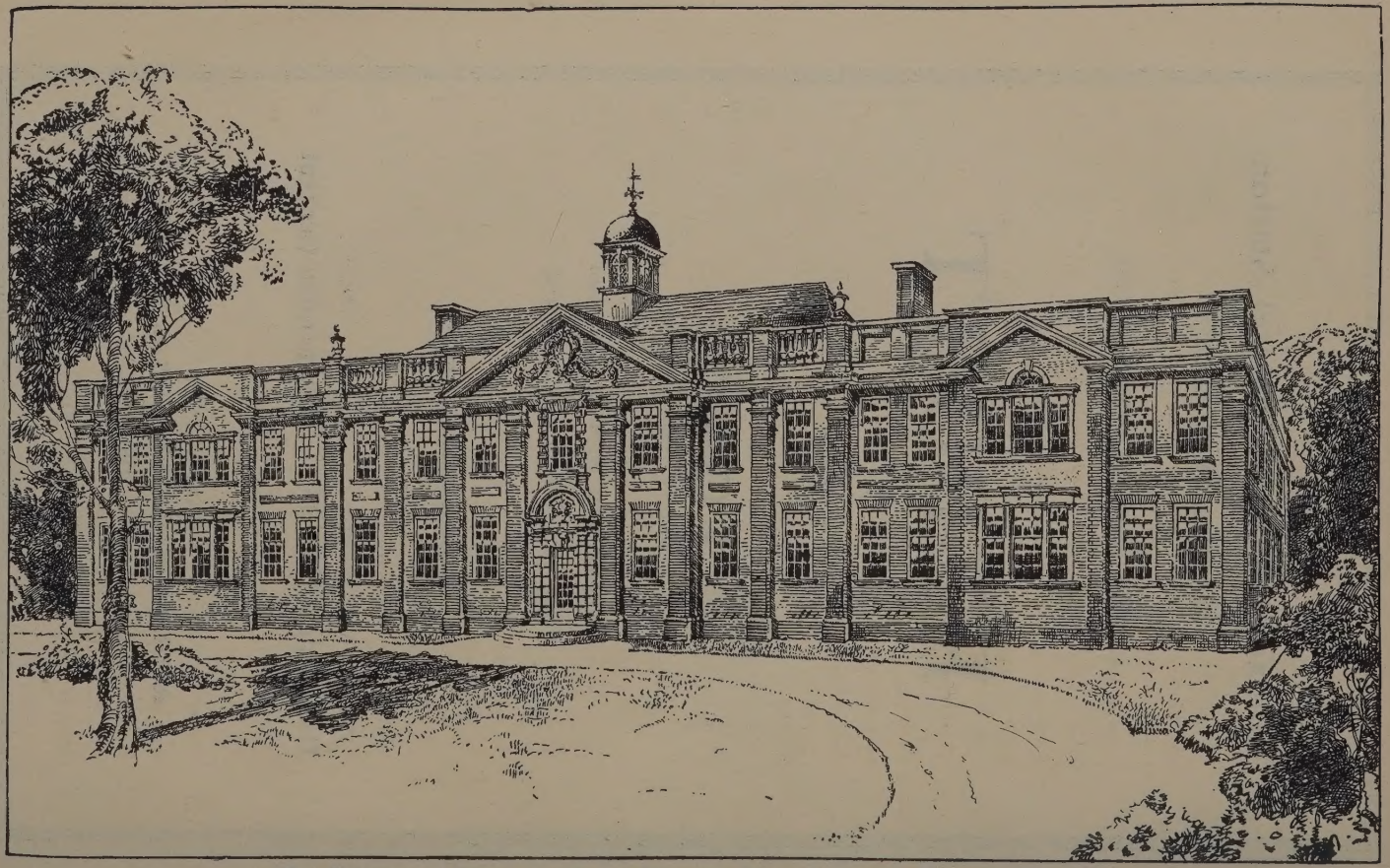

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914–1915.

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Indexer	...	Sophie Adams
Senior Clerk ...	...	Cynthia M. Horn
Clerks	...	Marguerita D. Payne, Iris Simpson, Rita M. Starkins

The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them and by rendering any technical assistance possible when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world, is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Commonwealth and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly sixty years. Lawes died in 1900, and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943, when the present Director, Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income from which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room and Conference Room.

Since 1945 Rivers Lodge, a house belonging to the Station, on the south side of the laboratories, has been used to provide accommodation for the Statistical Department.

In 1946 Rothamsted Lodge, the dower house of the Estate, was purchased and occupied by the Entomology and Bee Research and Advisory Department.

In 1947 the plant nematology work under Dr. T. Goodey, of the Institute of Parasitology, was transferred to Rothamsted, and a new laboratory was erected to house this department.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

A large new South Wing was completed in 1940, and the old chemical laboratories were reconstructed. These extensions and reconstructions have provided excellent accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments; in addition, a fine range of pot-culture houses was built. A new

laboratory has also been built and equipped for workers from the Imperial College of Science and Technology.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930–32 and equipped for electric light and power. Further additions were made in 1939–40, and the electricity supply has now been extended to these newer buildings.

A further range of six farm cottages was erected in Ninnings Field in 1948, and a concrete road constructed from the back of the laboratories to the farm.

The non-experimental part of the farm was reorganized in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but the Station also gains considerably by this closer association with the Universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934 the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted Estate were completed. The Rothamsted Trustees now own the site of the laboratories, the experimental and ordinary farm fields, Knot Wood, the Manor House and grounds, the farm manager's house and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers and from oversea sources.

During 1951–52 the Manor House was converted into a Hall of Residence, providing accommodation for seven families, rooms for twenty single workers and two guest rooms. Some of the large public rooms are available for lectures and general institutional purposes. The fabric of the older part of the building, part of which dates back to the 13th century, has been carefully preserved. The greater part of the cost was met by the Ministry of Agriculture, but the Station also received encouragement and financial aid from the Pilgrim Trust. The conversion has greatly enhanced the amenities of Rothamsted, and the accommodation is particularly useful for the younger members of staff and temporary workers from overseas. An illustrated guide to the Manor with an account of its history has been published (1953) under the title *The Manor of Rothamsted*.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually spreading out to the Commonwealth and other countries. The Station regularly participates in work for the solution of agricultural problems of great importance to the Commonwealth.

The Station offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soil Science, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

The Library

The Library may be said to have come into being in 1913, when the Sir Henry Gilbert Collection, presented by Lady Gilbert, was added to the small body of reference works used in the Laboratory at that time—most of them the gift of Sir John Lawes himself.

Its expansion, aided by gifts and grants from a number of individuals and Societies, was rapid, until it now contains :

	(Approximately)
Periodicals ... ... (Current, 1,500)	3,500
Books, 1841–	10,000
Books, 1471–1840 ... ... (including 14 incunabula)	3,500
Bound volumes of pamphlets	400
MSS.	100
Maps	300
Prints	100

—in all about 18,000 items, comprising some 50,000 volumes.

The yearly accessions of books and periodicals, bought and exchanged, amount to approximately 1,100 volumes.

The chief periodicals on agriculture and related subjects published throughout the world are received, either by subscription or in exchange, and constitute the most-used section of the Library.

The stock of books also covers a wide range of subjects—not only agriculture but also, e.g., chemistry, physics, biology, botany, geology, zoology, meteorology and statistics. The books are arranged according to the Universal Decimal Classification system. The collection of early printed books (1471–1840), which is kept separate from the rest, includes fourteen incunabula, amongst which is a copy of the first dated edition of Pier de' Crescenzi's *Ruralium commodorum libri duodecim*—the earliest printed book on agriculture —produced at Augsburg by Johann Schüssler in 1471 (Hain 5828). The collection of MSS. includes a copy of the *Treatise of Husbandry*, by Walter of Henley (fl. 1250), written in England on vellum about the middle of the 14th century.

The prints, which are mainly of the 18th and early 19th centuries, include portraits of eminent agriculturists, bucolic scenes, and representations of livestock. A most valuable addition to this collection was made in 1948, when Lord Northbrook presented his father's collection of prints to the Station.

The Library is designed to meet the requirements of the staff of Rothamsted; but its use is extended to any research worker who can show his need of it.

The General Catalogue of the Library is kept on cards. There is also a published catalogue of the collection of early printed books on agriculture (Rothamsted, 1926; second edition, 1940; Supplement, 1949). A complete catalogue of the serial publications in the Library is in the press.

INTRODUCTION

By The Director

It is with very deep regret that we record the deaths of Dr. Winifred E. Brenchley, Dr. Tom Goodey and Mr. Arthur Oggelsby, all of whom were held in affection and esteem by the staff. Dr. Brenchley, who retired from the headship of the Botany Department in 1948, came to Rothamsted in 1906, and was the first woman member of the staff. She not only achieved eminence in her subject but did a very great deal for the social life and welfare of the Station. Dr. Goodey, after two short periods of service on the staff (1912–13 and 1920–21), returned as Head of the newly-formed Nematology Department in 1948, but during the intervening years he was closely associated with Rothamsted, both socially and professionally. He was one of the leading nematologists in the world, and his friends will also remember his high spirits and his accomplishments as a singer and actor. Mr. Arthur Oggelsby, who gave many years of valuable service to the Chemistry Department and later was Head Storekeeper, retired in 1951 after fifty years at Rothamsted. He was one of the last links with our founders, for Sir Henry Gilbert was still Director when he joined the staff.

Sir Edward Salisbury, a representative of the Royal Society on the Lawes Trust Committee since 1940, retired from it during the year, and his place was taken by Sir Lawrence Bragg. Miss L. M. Crump, a member of the Microbiology staff since 1918, retired in October. In addition to her valuable scientific services, she took much interest in the library, particularly in the collection of early books. Dr. F. M. Roberts, of the Plant Pathology Department, who returned from secondment to the Clove Research Scheme, Zanzibar, resigned to take up a post in Jamaica under the Colonial Agricultural Research Service, and Dr. T. W. Tinsley's secondment to the West African Cacao Research Institute has been extended for a further tour of eighteen months. At the invitation of the Colonial Office and the Government of Nyasaland, Dr. A. Muir took charge of a soil survey of the Shire Valley area in connection with an extensive land development project; Dr. D. A. Osmond is in Cyprus for six months initiating a soil survey. Dr. J. Meiklejohn has returned after spending a year at the East African Agriculture and Forestry Research Organization, Nairobi, where she was working on problems of soil microbiology. Dr. P. S. Nutman, of the Microbiology Department, was awarded a three-year Senior Research Fellowship by the Commonwealth Scientific and Industrial Research Organization (Australia) to work in Canberra, and Dr. W. R. Smithies, of the Biochemistry Department, was awarded a one-year Fellowship of the National Research Council of Canada to work in the Council's Department of Applied Biology in Ottawa. Both are on leave of absence. Mr. B. W. Avery returned after spending a year with the Soil Survey of New Zealand in exchange with Mr. E. Cutler.

Several members of the staff made shorter visits abroad in connection with various projects. Dr. E. M. Crowther made a tour

in the Sudan and East Africa at the request of the Sudan Government, the Empire Cotton Growing Corporation and the Colonial Advisory Committee on Agricultural Research; he also attended a Specialist Conference on Fertilizers at the East African Agriculture and Forestry Research Organization and the Annual Research Meeting of the Sudan Ministry of Agriculture. Dr. F. Yates visited India at the invitation of the Food and Agriculture Organization of the United Nations to advise the Indian Council of Agricultural Research on the development of their Statistical Branch, and Dr. D. A. Boyd spent six weeks in Rome, Greece and Cyprus as consultant on experimental design to the F.A.O. Working Party on Mediterranean Pasture and Fodder Development. Mr. G. E. Hodnett was one of the instructors at an eight-week course held at the African Training Centre for Agricultural Statistics at Ibadan, Nigeria. Dr. B. G. Peters spent three months at the Connecticut Agricultural Experiment Station to advise on nematological problems, and Dr. C. B. Williams and Mr. R. A. French visited the Mediterranean coast to study the autumn southward movement of insects in that area.

Representatives from Rothamsted attended the Ninth International Genetics Congress and the Third International Biometric Conference, both held at Bellagio, and the Twenty-eighth Session of the International Statistical Institute in Rome; the Sixth International Congress of Microbiology and the Symposium on the Interaction of Viruses and Cells, which took place simultaneously in Rome; the Fourteenth International Congress of Zoology in Copenhagen; the Thirteenth International Congress of Pure and Applied Chemistry in Stockholm, and the meeting of the International Institute of Sugar Beet Research in Bergen op Zoom. Mr. F. C. Bawden accepted an invitation to participate in an International Symposium on the Dynamics of Virus Infection held at the Henry Ford Hospital, Detroit; and, at the invitation of the Research Council for Ontario, Dr. H. L. Penman attended a Meteorological Conference in Toronto. At the request of Professor E. C. Wassink, Director of the Laboratory of Plant Physiological Research, University of Wageningen, Dr. D. J. Watson gave lectures in a course on photosynthesis in Wageningen.

Dr. F. Yates was awarded the Weldon Memorial Prize given by the University of Oxford for outstanding work in biometrical science. Mr. M. H. Westmacott was granted leave of absence for six months to take part in the Everest Expedition. Sir William Ogg was elected President of the Society of Chemical Industry.

Visitors

There were several thousand visitors to the Station during the year, including many farmers. Amongst the overseas visitors were the Ministers of Agriculture from Norway and from Western Nigeria, the Yugoslav Ambassador, the Paramount Chief of Swaziland, the Senior Chief of Bechuanaland, the heir to the Paramount Chieftainship of Basutoland, the Secretary-General of the Israeli Ministry of Agriculture, the Under-Secretary of State for Agriculture and the Director General of the Agricultural Department of Siam, a party of six United States Congressmen and a group of

French Scientific Editors. Many organizations visited the Station, including the Institute of Biology, the Geological Association, the British Mycological Society, the Organization for European Economic Co-operation, the Empire Cotton Growing Corporation, the B.B.C. European Farm Organization and the Nuffield Foundation Survey Team of Architects. Overseas scientists who spent some time at Rothamsted included Dr. M. M. Burns, Principal of the Canterbury Agricultural College, New Zealand, Professor L. Davis of the University of California, Dr. Jonathan Garst of California, and Dr. C. S. Piper and Professor J. G. Wood of the University of Adelaide.

Buildings

Since the war there has been a rapid expansion in the scope of Rothamsted's activities. In addition to considerable growth in size of existing departments, two new departments, Pedology and Nematology, have been set up; two sections, Biochemistry and Bees, have been expanded into departments; the headquarters of the Soil Survey of England and Wales has been transferred to Rothamsted, and a Statistical Research Service has been set up in conjunction with the Statistics Department. As a result, the staff of the Station has more than doubled in numbers during the past ten years, and accommodation problems had become very acute. In order to meet the most pressing needs, several new buildings are being provided. One of these is the first instalment of a block which will ultimately house all the departments of the Plant Pathology group. Other buildings of a less permanent character are being erected to ease the congestion in the Statistics Department and to provide for fertilizer experiments and the work on the production of leaf protein. An extension of the Plant Pathology potting sheds and a new insectary have been completed. A historical account of the Manor of Rothamsted, now used as a Hall of Residence, has been written by Mr. D. H. Boalch, the Station's Librarian.

The Work of the Station

The **Pedology** Department is studying the weathering of rocks and the formation and classification of soils, and it works in very close association with the Soil Survey of England and Wales. Much attention is being given to soil and clay minerals, and the work is not confined to this country. Mineralogical studies of soils of the Athi Plain in Kenya and of the lower Shire River area in Nyasaland are throwing light on the nature of their parent materials. Good progress has been made in the survey of clay minerals, improvements have been made in techniques, and one or two new minerals discovered. These studies, which appeared somewhat academic, are beginning to have possible practical applications, for it has been found possible to characterize the clay mineral responsible for potash fixation in certain soils. Should this prove to be generally the case, we shall have a useful diagnostic criterion for this important soil property. A detailed comparison is being made of the soils in Broadbalk field and the adjoining strip (Broadbalk Wilderness), which has been uncultivated and under natural vegetation since 1882. There appears to be very little change either in the soil

profile or the composition of the clay, but the structure of the surface soil in the Wilderness has improved through an increase in organic matter. Investigations are being continued into the minor-element content of soils in various parts of the country, and a number of copper- and zinc-deficient samples from Wales are being studied. The work on soils with impeded drainage has been widened in scope, and interesting information obtained on the movement of iron and aluminium in the soil profile. Satisfactory progress has been made on the Soil Survey of England and Wales—nearly 300 square miles having been mapped in various parts of the country and advice and assistance given on several projects.

In the **Chemistry** Department much attention has been given to assessing by laboratory tests and field experiments the agricultural value of phosphate fertilizers insoluble in water. This is important at the present time, when attempts are being made by manufacturers to effect economies in sulphuric acid by using new processes which give high proportions of the phosphate in forms insoluble in water. Two series of co-operative field experiments planned and co-ordinated at Rothamsted have been carried out in collaboration with soil chemists of the National Agricultural Advisory Service, the Macaulay Institute and the Northern Ireland Ministry of Agriculture. The general results emphasize the outstanding merits of water-soluble phosphate on most classes of land, especially when used as a "starter dose" and placed close to the seed. Some of the insoluble forms, however, gave almost as good results as superphosphate for certain soils and crops. Three kinds of nitrophosphate, prepared by different processes, were tested on potatoes and grass. They differed amongst themselves, and all were somewhat inferior to superphosphate, especially on potatoes on neutral soils. It is too soon to come to definite conclusions, but the results obtained, so far, suggest that the phosphate in these materials has about the same effect as that in high-soluble basic slags. The nitrophosphates were granular, and the question arises whether water-insoluble phospates in granular form can act quickly enough in the early stages of crop growth. The experiments also indicate that greater use might be made of ground mineral phosphates on acid soils, particularly for swedes and established grass in the wetter parts of the country. For other crops a starter dose of soluble phosphate would be necessary. At current prices, including subsidies, this material costs only about a third the price of granular superphosphate per unit of phosphate. The results from many recent experiments show the need for a National Compound Fertilizer with high ratios of nitrogen and potassium to phosphorus.

Earlier work on fertilizer placement was extended. On the average of seven experiments on potatoes, light dressings of ammonium sulphate gave better results when placed and heavy dressings when broadcast. There was no advantage in holding back half the nitrogen until summer, even where the potato crop was regarded as maturing too early. Placed fertilizers gave better results than broadcast on lettuce, cabbage, beetroot, broad beans and runner beans. Further work on the manuring problems of forest nurseries has given additional evidence that conifer seedlings grow better when supplied with ammonium than with nitrate. Pot and field experiments using radio-phosphorus are in progress to assess the

availability of soil and fertilizer phosphorus to crops, and it has been shown that superphosphate combine-drilled with barley is utilized several times as efficiently as that broadcast. The investigations on soil organic matter and manganese have been continued.

Assistance has been given by the Adviser on **Tropical and Subtropical Soils,** both in the training of workers and in connection with the soil projects in various Colonies. Many Colonial soil workers spent part of their leave at Rothamsted discussing their problems in detail with the Adviser and other members of the staff, particularly those who have recently visited their territories. On the recommendation of the Soils Sub-Committee of the Committee for Colonial Agricultural, Animal Health and Forestry Research, approval has been given for the formation of a pool of three soil surveyors who will be available for periods of work in British Colonial Territories. At other times these surveyors will take part in the Soil Survey of Britain.

In the **Physics** Department a study is being made of the effect of organic matter on the crumb structure so desirable in soils, and a new laboratory test for estimating the strength of soil crumbs has been devised. Field experiments are in progress to study the effect of various crops on soil structure and, after two years under a grass ley, there is a distinct increase in the stability of the crumbs in the top 4 inches of soil. Further work has also been done on the structure of the land flooded by sea-water in February. It is well known that when rain has washed out the salt, heavy arable land may lose its crumb structure unless gypsum is applied before all the salt has gone. Calculations showed that, under the low rainfall of the East Coast, 2 tons per acre should in general have sufficed to prevent this during the past winter. More gypsum may still be required in certain cases, and a soil test has been devised which the National Agricultural Advisory Service can use to determine this. In the Woburn irrigation experiment the summer rainfall in 1953 was sufficient to maintain unrestricted transpiration, and calculated irrigation requirements were small and were not expected to lead to marked increases in yield. The early potato crop yielded 12 tons per acre without irrigation, but, with 2 inches of sprinkler irrigation, this was raised to 14·7 tons, and in seven cuts the gain from irrigating grass was 13 cwt. dry matter per acre. With sugar beet and barley there were no significant responses to irrigation in 1953.

Various soil micro-organisms produce substances (antibiotics) which might help to combat diseases in the roots of plants, and in the **Microbiology** Department further work has been done on this subject. It has been found that the production of antibiotics is influenced both by the strain of micro-organisms and by the type of soil—the effective action of many antibiotics being limited by the fact that they are rendered inactive by soil colloids. Nevertheless, in pot experiments with wheat, significant reduction of root diseases has been brought about in sterilized soil through the action of antibiotics produced by some strains of actinomycetes. Much of the work of the department deals with the nodule organisms of legumes. It has been shown that the number of nodules that develop on a root is determined more by the susceptibility of the root to infection than by the population of nodule bacteria surrounding it. It would also appear from studies on clover that hereditary factors

in the clover plant influence the time at which root nodules first appear, the number of nodules subsequently produced and their effectiveness in fixing nitrogen. Attention will no doubt be given to this by plant breeders, for it is desirable to have strains of clovers which freely produce nitrogen-fixing nodules. There can be competition between different nodule bacteria in the root surroundings, but it would appear that this is most acute amongst closely related strains. Experiments have shown no evidence of such competition between lucerne and clover bacteria, so it is unlikely that a legume crop will be harmfully affected in this way by a different legume previously grown on the same land. In view of the increasing use of insecticides and herbicides, the bacterial decomposition of these substances in the soil is also being studied in the department.

In the **Botany** Department work has been continued on plant nutrition, weeds and the physiology of virus infection. It has been shown experimentally that some of the ill effects caused by excess of manganese, molybdenum, and vanadium can be prevented by increasing the supply of iron. Further interesting information has been obtained on the effects of applying fertilizer solutions to leaves. Earlier experiments had shown that the protein content of sugar-beet tops could be greatly increased by repeated spraying of the leaves with solutions of urea in late September, and it has now been established that a single low-volume spraying with a concentrated solution is as effective as several sprayings with a dilute solution, although it may cause some scorching of the leaves. The potash content of lucerne was increased markedly by spraying with a solution of potassium sulphate, although the yield was unaffected; the same amount applied to the soil gave only a third of the increase in potash content. Beneficial results on plant growth, apart from the control of insect damage, from applications of insecticides containing phosphorus have been reported, but these have not been confirmed in experiments at Rothamsted. The work on wild oats suggests that it is safer to sow winter corn than spring corn where the land is infested with *Avena fatua*; the winter sowing appears to lead to lower germination and reduce production of new seeds.

Much of the work of the **Plant Pathology** Department is basic research on the nature of viruses, and during the year studies have been made of variations in infectivity of virus preparations, the rate of virus multiplication in plants and the effects of ultra-violet radiation on viruses and other proteins. The electron microscope is used a great deal in virus research, and improvements have been made in the techniques for preparing sections of leaf cells. On the more applied side, further work has been done on the exposure of plants infected with tomato bushy stunt, cucumber mosaic, tomato aspermy and two carnation viruses for two weeks to temperatures of 35° C. Some were completely freed from infection; in certain other cases virus-free progeny were established by taking cuttings from the heated plants. Heat therapy was not successful with plants infected with tobacco mosaic, potato X or spotted wilt viruses. It would appear that only viruses of spherical shape are inactivated by heat treatment; the practice fails with rod-shaped viruses, for they go on multiplying although adversely affected by the heat. Four viruses were isolated from commercial stocks of carnations. Two of these were the spherical type, and no insect vector has been

found for them. The other two are rod-shaped and transmitted by aphids; one of these was first recognized by serological tests and electron microscopy, and of the many plants to which it has been transmitted, only sugar beet has so far shown any symptoms. Studies of the viruses affecting cauliflower and broccoli have been continued, and it has again been shown that benefits are derived by surrounding seed-beds with barriers of barley. Turnip yellow mosaic virus was isolated from several species of cruciferous plants, and did much damage to some crops of broccoli in Northumberland. Further experiments with persistent insecticides applied to various crops, including potatoes, suggest that they have some value in decreasing the spread of viruses from infected to healthy plants, but they are largely ineffective in preventing infection by infective aphids arriving in a crop. In the sugar-beet crop attempts are being made to select breeding lines that either resist or tolerate infection with the yellows virus. So far, no resistance to infection has been found, but different lines varied greatly in their reaction to infection. This and other work suggests that there may be more than one cause for the disease now called yellows. The various methods which have been developed for controlling yellows in steckling beds are proving reasonably satisfactory.

In the Mycology section continued attention has been given to potato blight, and a piece of apparatus has been designed for use in studying the conditions favouring blight. It continuously records the amount of water that is deposited as dew or rain on potato shoots. Under the conditions at Rothamsted in 1953, spraying with copper fungicides and destroying the haulm with acid increased potato yields by only $\frac{1}{2}$ ton per acre, despite the earliest attack of blight for over thirteen years. Further work has been done on the incidence of powdery mildew on cereals, particularly on time of sowing in relation to the date of application of nitrogenous fertilizers. Experiments are also in progress on the effect of various crop rotations in freeing land from weeds and from fungi that cause root rots of cereals. It has also been confirmed that on land contaminated with take-all and eyespot, yields of grain were almost doubled by giving 4 cwt. of sulphate of ammonia per acre and decreasing the seed rate from 3 to $1\frac{1}{2}$ bushels per acre. It has been shown that there are physiological races of the fungus causing clubroot in turnip and cabbage. For instance, the variety of swede called Wilhelmsburger, bred for resistance to clubroot in Denmark, is very susceptible to the Norwegian form of club-root. The beneficial effects of dressing sugar-beet seed with a fungicide were again demonstrated, particularly for early sowing in cold ground. Work was started on the conditions that favour the rotting of sugar beet by the grey mould fungus (*Botrytis cinerea*), which threatens to become increasingly troublesome as mechanized harvesters become more widely used.

The **Biochemistry** Department is concerned mainly with enzyme actions, and those studied fall into three main groups. The first is ribonuclease, which digests nucleic acid. This substance is intimately connected with many cell processes, and particularly with virus infection; every plant virus that has been purified has turned out to be a ribonucleoprotein. The factors controlling the rate of destruction of normal nucleoproteins and of those connected with

virus infections are therefore of interest, and a knowledge of them must precede a rational approach to the cure of virus diseases. The second group of enzymes bring about oxidations. Part of this work is a prelude to the study of the formation of complex molecules such as the alkaloids. It is already clear that oxidation products of amino acids and their derivatives can undergo further oxidation in the cell and build up cyclic molecules. By suitable choice of starting material, it is probable that fairly elaborate molecules can be made. The plant hormones and growth regulators are also subject to enzymic oxidation, and this may be part of the normal mechanism by which their concentration is controlled, and if so, these enzymes play a part in regulating the growth of the plant. The third line of work is an investigation of the breakdown of cellulose and chitin by enzymes. Cellulose is a characteristic component of the residues of plants, and chitin is present in fungal residues and those of most soil fauna; both may be of importance in the formation of soil organic matter. Enzymes, from soil organisms and from other sources, are being used to throw light on the natural course of breakdown of both substances in the soil and on the nature and composition of the cell walls and other structures in which they are found. Knowledge of the chemical behaviour of the various intermediates is expected to elucidate some aspects of the binding of trace elements, phosphorus and other nutrients in the soil. During the past year little practical work has been done on the pilot-plant production of leaf protein, but some machinery has been installed, and other equipment, both for production and for the control of the operations, is being designed and made.

It is important to be able to assess the number of potential eelworms (living eggs or larvae) in samples of soil. This is a tedious and time-consuming business, and in the **Nematology** Department a good deal of attention has been given to improving and speeding up the methods. One of the most promising approaches to control of eelworms is to find varieties of crops which are resistant and, in co-operation with the National Institute of Agricultural Botany, work is in progress along these lines. Numerous new oat varieties have been tested for resistance to stem eelworm, and one spring and and two or three winter varieties show promise. A race of the same species of eelworm (*Ditylenchus dipsaci*) attacks lucerne, and in preliminary trials two varieties of lucerne and most other legumes were found to be resistant. Twenty-four commercial varieties of potatoes were tested for resistance to the related potato tuber eelworm, but not one was resistant. There is a plant of the potato family from South America (*Solanum andigenum*) which shows resistance to potato root eelworm, and plant breeders are using this for crossing, in an attempt to get the resistance factor into cultivated potatoes. In the Nematology Department the nature of this resistance is being studied. It appears that the eelworm larvae can penetrate the roots of *S. andigenum*, but most of them fail to become adult. Resistance to cereal root eelworm is being studied in twenty-one varieties of barley and seventeen varieties of spring oats, in conjunction with the National Institute of Agricultural Botany and the National Agricultural Advisory Service. Eelworm attack can also be controlled by suitable crop rotations, and

changes in the populations of potato root eelworm and cereal root eelworm under various rotations are being investigated at several centres. Work is also in progress on the root diffusates which stimulate hatching of cysts and on the control of eelworms by applying various chemicals to the soil.

In the **Entomology** Department further work has been done on insect migration and on the influence of weather conditions on insect populations. Many insects, harmful and beneficial, move southward in autumn over long distances and in vast numbers. In order to study this a small expedition was made to the Pyrenees, and extensive movement over a period of at least five weeks was observed of about a dozen species of Lepidoptera (including Small Cabbage White Butterflies and Silver Y Moths, both pests in Britain and Central Europe) and various species of Diptera (including Hoverflies of two groups, those that eat aphids and those that live on decaying vegetation and manure). In another investigation it has been shown that certain caterpillars grow and develop more rapidly when crowded together—an abundant population thus tending to become more abundant. The work on gall midges of economic importance has been extended, especially on grass seed midges, the lucerne leaf midge, and those attacking chrysanthemums. The biology of a species of midge which attacks the lower parts of the stems of grasses and cereals is being studied, and the range of host plants, of this and various other midges, investigated. Experiments have shown that the very injurious sorghum midges that are now causing great trouble in West Africa can survive for over nine months on sorghum heads in this country, and it may be possible to give some assistance on this problem. Work on aphids has been continued, and it has been shown that they can take off from their host plants during much higher wind speeds than was previously thought. It would also appear that aphids normally do not reproduce until they have made a flight, however short. The destruction of aphids by ladybirds and hoverflies is largely dependent on the number of these predators at the beginning of the season, and hence on the survival of adults from the previous year. In co-operation with the Insecticides Department and the National Agricultural Advisory Service, work has been commenced on the wheat bulb fly, and methods devised for rearing the flies in captivity, thus facilitating a study of their biology. In the wireworm investigation it has been found that, under a dense vegetation cover, there is very little movement of adult beetles, and with the Insecticides Department further work has been done on the chemical control of wireworms. The forest soil studies have been continued with particular reference to the activities of mites in natural and afforested heathland.

The main lines of work in the **Bee Department** concern the behaviour and diseases of bees and the pollination of red clover. In work on queen introduction, it has been shown that queen honeybees produce a substance (" queen substance ") which the worker members of their colonies urgently seek. This substance is the factor controlling the production of supersedure and emergency queen cells and probably plays an important part in swarming. So long as each worker obtains sufficient " queen substance " she is inhibited from building these cells and from tolerating the presence of eggs or larvae in swarm queen cells. The " queen substance " of virgin queens

appears to differ from that of mated queens, but probably all virgin queens produce one kind and all mated queens another. It is suggested that the craving for " queen substance " is the most important factor in the maintenance of colony cohesion in honeybees, ants, and termites. The results of these and earlier observations have led to experiments on a simple and most economical method of queen introduction with which very satisfactory results have so far been obtained. Of 230 mated queens, including nearly 100 that had been in transit or caged in the laboratory for as long as five days, all except one have been introduced successfully. During the last few years it has been claimed that an anaesthetic prepared by adding crystals of ammonium nitrate to burning fuel in a beekeeper's smoker has very valuable practical applications. The active agent was said to be nitrous oxide, and the treatment was also claimed to cause loss of memory, so that when a colony were moved to a new position the bees did not drift back to the old site, even if it were close at hand. Work at Rothamsted has shown that the main anaesthetizing action must be due to other substances, as nitrous oxide has little effect on honeybees, that the fumes contain harmful cyanides and that little, if any, inhibition of drifting is obtained. Nevertheless, if used with great care, this method of anaesthetizing colonies of bees *in situ* is probably the most effective known.

Observations on worker bees visiting dishes of sugar syrup indicate that, even when a bee has become aware of a richer store of food, she may continue to forage from another source to which she is more accustomed. Investigations into the causes of swarming suggest that, whilst overcrowding of the bees in the hive predisposes a colony to swarm, an excess of bees to brood has little, if any, such effect. Work on the pollination of red clover has been continued, and it has been shown that although fertilizer treatment of the crop does affect nectar secretion, much greater differences are found between clones receiving the same treatment. This indicates the possibility of selecting strains of red clover more attractive to pollinating insects. Further studies have also been made on the pollination activities of bumble bees on this crop. In the bee disease work it has been shown that Nosema disease is carried over from one year to the next on old combs and that infected bees do not transmit it to any extent at times of the year when they can fly freely. The transference of all the adult bees of an infected colony to clean comb in spring is sufficient to eliminate this disease from the colony. This procedure seems likely to be more satisfactory than the use of drugs. A successful method has been found of treating old combs from infected colonies with vapour of either formaldehyde or acetic acid.

The **Insecticides** Department is concentrating on the study of the various factors—biological, chemical and physical—which determine the action of insect poisons. This type of work should enable existing products to be used more safely and effectively and also put the search for new and better materials on a more rational basis. Work is being carried out on the following groups of insecticides : (1) chlorinated hydrocarbons, chiefly D.D.T. and related substances; (2) organo-phosphorus compounds, including those which are taken up by the plant and render it poisonous; (3)

natural pyrethrins and allied substances. Laboratory experiments are in progress on materials of the D.D.T. group to throw light on the effect of particle size of suspensions, for this influences both the amount of poison retained on the body of the insect and its effectiveness. The persistence and toxicity of deposits of these substances on leaf surfaces is also being studied. Strains of insects resistant to insecticides are becoming a serious problem, and attempts are being made to find out what favours the occurrence of a resistant strain. In the organo-phosphorus group further work has been done on the insect enzyme systems that are acted on by these compounds. A good deal of attention continues to be paid to the pyrethrin group of insecticides since they are so safe to use. The relationship between the structure of the molecules in this group of substances and their insecticidal action is being investigated. The four known active constituents which occur in Pyrethrum flowers have been isolated for the first time, and their properties are being studied. Although they differ in toxicity, all are highly effective. Some assistance has been given to the Kenya Pyrethrum Board in their endeavour to improve the strain of plant that is grown. On the field side, experiments on the control of bean aphis, wireworms and the aphids which transmit potato viruses have been continued. The wireworm results for 1953 again indicated that insecticides drilled with the seed gave protection for subsequent crops which a seed dressing failed to do. In collaboration with the Seale–Hayne Agricultural College further work has been done on the effect of plant protective chemicals on honeybees.

There have been no major changes in the work of the **Statistical** Department during the year. One of the problems being studied is the amount of experimentation economically justified when questions of immediate practical importance have to be settled. The future of a number of the long-term Rothamsted and Woburn experiments is being reviewed and a plan drawn up for the re-design of the Classical rotation experiment on Agdell field. As in the past, much assistance has been given to other departments at Rothamsted, the Colonial Office and the National Agricultural Advisory Service. Reports have been prepared on sugar-cane experiments and help given in connection with experiments on the manuring of rubber. A survey of hill and livestock rearing farms has been begun with the object of finding out how far improvements under the Hill Farming and Livestock Rearing Acts have affected the production, economy and working conditions. The surveyors are also estimating the scope for further improvements. The survey of fertilizer practice has been extended to eight more districts which had not previously been examined or had not been surveyed for many years. A report has been published on the 1952 survey of rabbit damage to winter wheat; a close correlation was found between rabbit grazing observed in January and the final loss of yield. On the animal production side, surveys are in progress, in conjunction with the Veterinary Laboratory, Weybridge, on diseases of dairy cattle, and assistance has been given to the Ministry of Agriculture, Northern Ireland, in the planning of a survey of diseases and husbandry practices of cattle, sheep, pigs and poultry. The survey of bloat carried out in Wales in 1952 has been reported on and further work carried out, and, in co-operation with the Veterinary Investigations

Officer at Leeds, a survey has been made of the incidence of loss in pregnant ewes in Yorkshire.

An extensive programme of **Field Experiments** at Rothamsted and Woburn was carried out successfully. The cool, moist summer favoured roots and grass, and there were also good yields of cereals in spite of some lodging. The section of Broadbalk field immediately following the fallow had its worst attack of wheat bulb fly so far observed, and the fly is being studied on this field and on neighbouring areas. In addition to the Classical and other long-term experiments, many shorter experiments were undertaken. Some of these have already been mentioned. On the nutritional side they included studies of nitrophosphates and fertilizer placement, on the pathological side, eyespot in wheat, late blight in potatoes, virus spread in sugar beet, potatoes, and broccoli, mildew in wheat and barley, wireworm in wheat and aphis in field beans. For several seasons the residual effect of dung applied to potatoes has been measured in the following wheat crop, and again in 1953 dung was shown to have an appreciable effect, although the wheat had received a good dressing of fertilizers. Measurements of the effect of top dressings of " Nitro-Chalk " applied to cereals in late June after the ears had emerged confirmed that the nitrogen was utilized better by barley than other cereals. There was an increase in crude protein of 1·3 cwt. in the barley grain plus straw as a result of applying 3 cwt. of " Nitro-Chalk " per acre, a recovery of about 45 per cent of the added nitrogen. Experiments were commenced to see whether top dressings of either sulphate of ammonia or muriate of potash, applied just before the final earthing-up, would prolong the life of potato plants and thereby increase yields. Neither fertilizer had any effect in 1953, but the experiment will be repeated.

At Woburn in 1952 part of the permanent barley plots, sown with winter barley, gave much better results than spring barley, and it was thought that this might have been due to the winter barley suppressing weeds. Further work in 1953, however, suggests that winter barley is not superior, and that the differences can be accounted for by variations in acidity within the plots. The study of the effect of irrigation on the proportion of grasses and clovers in repeatedly cut leys has been continued, and although with the well-distributed summer rainfall in 1953 there appeared to be no check on growth, even on the dry plots, irrigation as in previous years raised the proportion of clover, though to a much smaller extent. Work on maize grown for grain has been continued at Woburn for fifteen years. The past season was a difficult one, owing to the long, cold spell in spring and early summer; nevertheless, certain hybrid varieties, acclimatized in Europe, yielded up to 31 cwt. of dry corn per acre, and it is clear that there are now types which, under proper management, can give an economic yield, even in an unfavourable year. In tests with sweet lupins for green fodder, yields of 2·7 and 3·4 tons dry matter per acre were obtained, and further work with serradella indicates that it may be a useful fodder crop on light acid land.

There has been a gratifying amount of co-operation between departments and also with the Farm Manager and his staff.

PHYSICS DEPARTMENT

R. K. Schofield

Thanks to financial support from the Research Council of Ontario, H. L. Penman was able to attend a meteorological conference in Toronto, to meet and visit Canadian workers in agricultural meteorology, and to visit four American centres of research in agronomy, hydrology and agricultural meteorology. At the request of the Research Council he prepared a report making recommendations for future research activity in agricultural meteorology in Ontario. He wishes to record his sincere thanks to the Council for their great generosity in sponsoring the visit, and to all in Canada and the U.S.A. who made a crowded trip so happy and rewarding.

H. R. Samson received the Ph.D. degree of London University, and returned to resume his duties with the Ceramics Section of the Australian Commonwealth Scientific and Industrial Research Organization. I. R. Cowan has transferred to the Sugar Research Department, Mandeville, Jamaica, where he will work under Mr. R. F. Innes with general guidance from Rothamsted. J. M. Bastos de Macedo, of the Instituto Superior de Agronomia, Lisbon, worked for seven months on the sorption of phosphoric acid by the different crystalline forms of ferric oxide which occur in tropical soils, and he will continue this work in Lisbon. F. Silva, of Medellin University, Colombia, has joined the department for ten months, having won a British Council Studentship.

J. L. Monteith joined the staff, but continued for a few months his work under Professor P. A. Sheppard at the Imperial College of Science. J. S. G. McCulloch visited agricultural meteorological stations in Germany with the assistance of a travel grant from the Agricultural Research Council.

Agricultural Meteorology

(H. L. Penman)

Irrigation

The summer rain in 1953 was sufficiently plentiful to reduce the irrigation requirement to very low values. Indeed, by ordinary

Woburn Irrigation 1953

Crop	Period	Rain, inches	Irrigation, inches	Plot	Yield
Grass	27 Apr.–28 Sept.	12·1	—	ON_1 82·2	Dry matter (7 cuts), cwt./acre
				ON_2 95·0	
		12·1	5·6	CN_1 91·7	
				CN_2 108·4	
Sugar beet	27 Apr.–28 Sept.	12·1	—	ON_1 81·0	Sugar, cwt./acre
				ON_2 87·3	
		12·1	3·6	CN_1 80·1	
				CN_2 83·2	
Barley	27 Apr.–10 Aug.	7·4	—	ON_1 23·7	Grain, cwt./acre
				ON_2 30·0	
		7·4	0·8	CN_1 23·8	
				CN_2 29·0	
Potatoes	27 Apr.–6 July	4·5	—	ON_1 10·1	tons/acre
				ON_2 12·0	
		4·5	2·0	CN_1 12·0	
				CN_2 14·7	

farming standards it was a summer in which irrigation would be dismissed as unnecessary. The table on p. 35 shows the yields for the watering extremes at two levels of nitrogen dressing.

Notes on weather and crops :

Weather. Rainfall was not much above average at any time, but evaporation conditions were poor, so that soil moisture deficits never became very big.

Grass. The seventh cut was late in October. The maximum irrigation was deliberately overdone, and lower rates were almost as effective : e.g., for 2·6 inches of irrigation the yields were : AN_1, 91·3; AN_2, 101·9 cwt. dry matter per acre. During the summer H. H. Mann has continued to keep his records of the content of grass, clover and weeds in the herbage.

Sugar beet. Irrigation was unnecessary.

Barley. The irrigation schedule had to be abandoned in June because of lodging on all the plots, but which was most severe on the high nitrogen halves.

Potatoes. A very good yield without irrigation was made even better by keeping the soil close to field capacity throughout the growing season.

With a new rotation starting in 1954 some changes are being made. The grass plots will be ploughed up and re-seeded with a pure grass strain; main crop potatoes will replace earlies; and a winter cereal will replace barley.

Micro-meteorology

I. F. Long has maintained the continuous recording of dry and wet bulb temperatures within and above the potato crop used for blight studies. To this equipment he has added continuous recorders for wind of his own design and building. This was first successfully tried at East Malling, where the equipment was set up at blossom time to help Dr. Rogers get a measure of air movement among apple-trees on nights of radiation frost. It was then used at Woburn along with a duplicate set of temperature and humidity recorders in a first attempt to find out what difference irrigation makes to the micro-climate of the crops irrigated. In this wet summer no differences were detected.

Transferred to Rothamsted potatoes in late summer, the wind recorders have usefully supplemented the other information about dew formation and vapour-pressure gradients. An account of this work was given at the Toronto Conference. Although there may be wide variations, a typical " dew " night has the following character : about sunset the wind drops quickly, the atmosphere in and above the crop is saturated, but there are vapour-pressure gradients such that vapour moves to the crop canopy from the air above and from the soil beneath. Condensation takes place at a fairly uniform rate until about sunrise, when there is a simultaneous rise in temperature and in wind speed, and a relatively rapid re-evaporation of the dew, completed in about 3 hours, the final phases of which coincide with a change from saturation to non-saturation in the ambient atmosphere.

Heat flow in the soil

J. S. G. McCulloch has made an intensive study of the causes of the anomalies found in deriving thermal diffusivity from records of daily amplitude and daily phase of temperature waves in the soil. These anomalies are attributed to the variation of the " constant " with depth, and standard theory has been modified to take account of this variation with depth in a way that makes no initial assumptions about its form. The final expression for the diffusivity is essentially the same as one due to Dr. Peerlkamp of Holland, unknown to us until recently. The main immediate application of the new theory is in determining the effect of changes of water content on thermal constants of the soil.

Soil Physics

The effect of organic matter on crumb cohesion

Previous methods for measuring crumb cohesion, such as wet sieving, have not distinguished between the breakdown of crumbs on wetting, due to entrapped air (slaking), and that produced by subsequent mechanical dispersion of the wetted crumbs. From the previous year's work on the dependence of slaking on the rate of wetting, W. W. Emerson concluded that under the low intensity rainfall conditions prevailing in England, slaking would be a relatively unimportant cause of crumb breakdown.

A test was needed, therefore, which would measure only the resistance of crumbs to dispersion. It was found that natural soil crumbs, which are effectively calcium saturated, would not disperse in very low concentrations of calcium chloride unless mechanically disturbed. This accounts for the dependence of the results obtained by wet sieving on the particular way in which the sieves are agitated. However, if the soil crumbs are sodium saturated, swelling and then dispersion occur spontaneously as the crumbs are flushed with successively lower concentrations of sodium chloride. The degree of dispersion at any particular concentration is an index of the stability of the crumbs.

This technique has been used to study soil samples taken from grass and lucerne plots laid out on a field which had been in arable cultivation for many years. This soil contains calcium carbonate. Two to four years under grass have materially increased the cohesion of the surface crumbs compared with crumbs from adjoining fallow strips. As might be expected from the preponderance of roots in the surface layers, the improvement in soil cohesion is much greater at 0–4 inches compared with the deeper soil layers.

The practical importance of increased crumb cohesion has still to be evaluated. *A priori*, less panning of the surface soil should occur, leading to better germination and growth due to improved root aeration. The four-year-old plots have been ploughed, and the growth of crops on these and the fallow strips will be compared.

Delayed swelling

Soil crumbs dried initially to the wilting point have been slowly percolated with $1 \times 10^{-2}M$. calcium chloride through a capillary siphon. It has been shown by weighing the crumb at intervals that

although excess solution is discharged from its base, after the first or second day the crumb continues to take up solution at a decreasing rate over the next three months. This is attributed to the rearrangement of the individual clay crystals, as the thickness of the water films on the crystals increases with decreasing suction. It has been shown theoretically that the equilibrium thickness of these films will increase markedly as the suction approaches zero.

The slow swelling of the clay will be accompanied by a corresponding decrease in the permeability of the crumbs as the larger pores are reduced in size. This is of great practical importance in the drainage of heavy clay soils, since it means that the permeability of the soil as a whole may be improved over the winter by using a deep-rooted crop to dry the subsoil out during the summer. This has been shown by comparing the drainage records of three fields : one after fallow, one after winter wheat and the third in permanent grass on the Gault of the Cambridge University Farm for the winter of 1932–33. It was also possible to infer from the dates at which the drains started running and the volume of water discharged that considerable delayed water uptake occurs as the clay slowly swells.

Delayed swelling also affects the concept of field capacity, since the moisture content of the soil at " field capacity " will increase during the winter with each succeeding fall of rain. Penman's * attempt to forecast the running of mole drains has been re-examined in this light.

The time taken for clay to swell partly explains why mole draining is successful at all and why it is preferable to mole in the spring rather than in the autumn. The gradual reduction in the cohesion of crumbs as the clay slowly swells may be important in some engineering problems.

Positive charges on the edge faces of clay crystals

G. H. Cashen has endeavoured to get further evidence for the existence of positive charges on the edge faces of clay crystals. Schofield and Samson (1953) gave reasons for thinking that at least a part of the buffer action of kaolinite is due to proton transfer at the edge faces. In order to accentuate the influence of the positive charges, the effect of the larger negative charges associated with the cleavage faces has been progressively suppressed by the addition of graded amounts of an organic cation (*cetyl trimethyl* ammonium). In this way the normal lowering of pH when KCl is added to a clay suspension has been reversed. The results are not yet entirely satisfactory owing to a troublesome drift in the pH values.

Physical Chemistry

Soil tests for flooded land

A. W. Taylor has worked out the details of a method devised by R. K. Schofield for measuring the deficit of divalent ions in a soil which has been flooded by sea-water. This method (modified slightly for convenience in routine testing) will be used by the National Agricultural Advisory Service to test heavy land which may require more than the standard dressings of gypsum in order to prevent breakdown of structure during the next few years.

* *J. Soil Sci.* (1949), **1**, 74–89.

Many soil samples were taken by N.A.A.S. officers from the land after the flooding, and the chloride contents of these samples were determined in N.A.A.S. laboratories. This information was of considerable value as a guide to the chances of successful cropping in 1953 when plant growth was mainly affected by the salt content of the soil. In a general way it was to be expected that high salt content would run parallel with the degree of replacement of divalent cations by sodium which, if not corrected by application of gypsum, would ultimately result in loss of soil structure. Provision was therefore made for the application of 2 tons per acre of gypsum to all arable land containing more than 0·1 per cent of sodium chloride in the top 6 inches.

It was believed that this gypsum dressing would be sufficient to safeguard the structure of considerable areas, but that more would subsequently be required on some of the heavy lands. A test was needed that would, in effect, determine the amount of exchangeable sodium, but no satisfactory laboratory method was available.

Although the development of the flame photometer has revolutionized the determination of sodium, the difficulty is to determine how much of the total sodium in the soil sample is present as salt, which in itself is no danger to soil structure, and how much is present as exchangeable sodium, which is potentially injurious.

A practical solution to the problem has been found through measuring the quantity of divalent ions which the soil sample can *take up* rather than the sodium given out in the exchange reaction. It is logical to recommend a field application of gypsum equivalent to the amount which can be seen to react with the soil sample under laboratory conditions. Moreover, since field conditions are never as favourable for complete reaction as those which can be arranged in the laboratory, this method of test will tend to underestimate the amount of gypsum which could give maximum benefit in the field. Furthermore, in calculating the field dressing a somewhat arbitrary figure must be taken for the depth to which it is considered necessary for the reaction to proceed.

In spite of these obvious limitations, it is hoped that the test will prove useful.

Soil solution equilibrium

The acquisition of a flame photometer has greatly facilitated the determination of K and Na at low concentrations, while the development and refinement of the versenate titration has facilitated the estimation of Ca and Mg. A critical examination of the soil/solution equilibrium, which was formerly impracticable, is now under way.

CHEMISTRY DEPARTMENT

E. M. Crowther

Alternative phosphate fertilizers

The phosphates in most British compound fertilizers are derived from superphosphate or ammonium phosphate and are valued in terms of a water-solubility test, but in many other countries phosphates insoluble in water are classed with water-soluble compounds as " available phosphoric acid " in assessing fertilizer values. In the United Kingdom the citric acid test is used for basic slags, and it is known to distinguish fairly sharply between the active silicophosphates and the almost inactive fluorapatite in Open Hearth basic slags. The citric acid test is of little, if any, use in characterizing ground phosphate rocks, because the amounts dissolved vary markedly with the conditions of extraction.

A universally applicable method for evaluating phosphate fertilizers would be of great assistance to farmers and their advisers, and especially to manufacturers conducting pilot-plant investigations on new processes, but there is a serious risk of error if the analytical method chosen should prove to be inappropriate for any important type of soil or class of product. The availability of phosphate fertilizers to crops involves so many complex factors that laboratory methods should be checked and standardized by the results of direct comparisons of fertilizers in field experiments under a wide range of conditions. This is of special importance at the present time, when attempts are being made in several countries to effect economies in sulphuric acid by using new processes which give products with high proportions of their phosphate insoluble in water. Before such materials are produced and sold on a large scale it is important to know how they compare in the field with superphosphate supplying equal amounts of phosphorus, for the newer processes are not likely to succeed unless the products prove to be at least as economical as superphosphate.

In order to obtain basic data on these general questions, several series of co-operative field experiments have been conducted with associated laboratory work. E. M. Crowther, R. G. Warren and G. W. Cooke have published a detailed account (21) of field experiments on materials of special interest during the war and the following years. Since 1951 two new series of field experiments, initiated by the Fertiliser Conference of the Agricultural Research Council and planned and co-ordinated from Rothamsted, have been conducted annually by the soil chemists of the National Agricultural Advisory Service and the staffs at the Northern Ireland Ministry of Agriculture, the Macaulay Institute for Soil Research and the Rothamsted Experimental Station. G. W. Cooke has prepared the following interim summary of the results so far to hand. Both series of experiments were in 6×6 Latin Squares with superphosphates at rates of 0, 1, 2 units of P_2O_5 and three other phosphates equivalent to 1·5 units. All plots received equal amounts of nitrogen and potassium.

The results are summarized below as crop yields and as " percentage superphosphate equivalents ", the latter figures giving

the amounts of superphosphate found graphically to give the same mean yields as one hundred parts of the fertilizer tested.

TABLE 1

Experiments on potatoes (1951–53) *and swedes* (1951–52)

Cwt. P_2O_5 per acre		Potatoes on very acid soils (pH 5·5 and less)	Potatoes on acid soils (pH 5·6–6·5)	Potatoes on neutral soils (pH over 6·5)	Swedes
	No. of experiments :	10	15	9	24
	Yields in tons per acre				
—	No phosphate	9·2	9·8	9·1	11·6
0·33	Superphosphate	10·9	10·9	9·9	17·2
0·66	Superphosphate	11·6	11·2	10·3	19·7
0·5	Dicalcium phosphate	11·5	10·9	10·0	18·3
0·5	Silicophosphate	11·2	10·8	9·6	18·1
0·5	Gafsa phosphate	10·3	10·6	9·2	18·1
	Percentage superphosphate equivalents				
	Dicalcium phosphate	122	62	88	90
	Silicophosphate	92	56	30	87
	Gafsa phosphate	34	37	4	87

The results of the first series of experiments on potatoes and swedes are given in Table 1, the potato experiments being grouped by soil reaction. Most of the swede experiments were on soils with pH values between 5·5 and 6·0. Dicalcium phosphate, which is highly soluble in citric acid or neutral ammonium citrate but not in water, was used in a finely divided form, and gave results only slightly inferior to those from equivalent superphosphate for both crops on all classes of soils. Silicophosphate, prepared by heating phosphate rock with sodium carbonate and also without water-soluble phosphate, gave almost as good results as superphosphate for potatoes on very acid soils and for swedes, but was markedly less active than superphosphate for potatoes on moderately acid or neutral soils. Ground Gafsa mineral phosphate gave very good results on swedes but poor ones on potatoes, even on very acid soils. This material is not expected to work on neutral soils. With current subsidies unit phosphate in ground Gafsa mineral phosphate costs only about one-third as much as that in granular superphosphate, and there would therefore seem to be a good case for using mineral phosphate much more extensively on the large areas of acid soils which remain in the hill lands of the wetter areas. Ground mineral phosphate could serve as the only source of phosphate for swedes and established grass, but for other crops, including the seeds for leys, it would need to be supplemented by a moderate dressing of a soluble phosphate as a " starter-dose ".

In several countries compound fertilizers—" Nitrophosphates " —are being made by using nitric acid in place of sulphuric acid to attack the phosphate rock; ammonia is added to neutralize the excess acid and form dicalcium phosphate and ammonium nitrate, but it is also necessary to reduce the content of soluble calcium salts still further. In one process excess calcium nitrate is removed before adding the ammonia. In others calcium sulphate is formed by using a mixture of sulphuric acid and nitric acids or by adding

ammonium sulphate. As the products are granular, the important question arises whether the insoluble dicalcium phosphate can act quickly enough where early establishment and growth are important.

TABLE 2

Experiments on potatoes and grass (1952–53)

Cwt. P_2O_5 per acre		Potatoes on acid soils (pH 6·5 and less)	Potatoes on neutral soils (pH 6·6 and over)	Grass
	No. of experiments :	11	7	20
	Yield in tons per acre			
—	No phosphate	9·7	10·7	2·33
0·3	Superphosphate	10·7	11·3	2·51
0·6	Superphosphate	11·6	12·1	2·52
	Nitrophosphate made by :			
0·45	Adding ammonium sulphate	11·0	11·2	2·50
0·45	Using nitric and sulphuric acids	10·7	11·2	2·47
0·45	Removing calcium nitrate	10·2	11·0	2·46
	Percentage superphosphate equivalents			
	Nitrophosphate made by :			
—	Adding ammonium sulphate	88	51	—
	Using nitric and sulphuric acids	66	52	—
	Removing calcium nitrate	34	20	—

Three kinds of Nitrophosphate were compared in the co-operative trials of 1952 and 1953, with results set out in Table 2. All three Nitrophosphates proved to be inferior to superphosphate for potatoes, especially on neutral soils. There were also marked differences between the three kinds of Nitrophosphate, the one made by removing calcium nitrate being inferior to the other two. The grassland experiments were very insensitive, with negligible benefits from increasing the superphosphate dressing. Although the differences were very small, the order of the Nitrophosphates was the same as for the average of the potato experiments. These results suggest that producers of Nitrophosphate or similar fertilizers should not value the phosphate at more than about three-quarters of water-soluble phosphate. Further, it may be misleading in pilot-plant developments to rely on the citric acid tests. The product made by adding ammonium sulphate had 28 per cent of its phosphorus in a water-soluble form, and the other two had almost none, but only 89 per cent of its phosphorus was soluble in citric acid, as compared with 100 and 96 per cent in the two products which behaved less well in the field. The behaviour of dicalcium phosphate in granular fertilizers needs much more detailed investigation in the laboratory and the field in relation to the precise form of the crystals, the physical conditions of the granules and the nature of the other salts present before it would be safe to rely on laboratory methods to characterize the products. The necessary field work, laborious and expensive as it is, should be regarded as part of the developmental costs to be incurred before a new kind of phosphate fertilizer is introduced. For farmers and their advisers it would appear that the phosphate in Nitrophosphate behaves in much the same way as that in high-soluble basic slags. These

two classes of fertilizer have not been compared directly, since they are normally used in different ways.

The general results of both series of experiments emphasize the outstanding merits of water-soluble phosphate on most, if not all, classes of land. Although other tests are needed for certain special classes of phosphate fertilizer, formal simplicity should not be secured at the cost of sacrificing the water-solubility test for superphosphate, ammonium phosphate and mixtures based on them.

Fertilizer placement

G. W. Cooke with F. V. Widdowson and J. C. Wilcox tested a Nitrophosphate (made with the addition of ammonium sulphate) against an equivalent mixture of granular superphosphate and " Nitro-Chalk ", both lots being applied broadcast and combine-drilled. On the average of five experiments on spring cereals, Nitrophosphate was of little value when broadcast and better, though still inferior to the superphosphate and " Nitro-Chalk ", when combine-drilled. The mixture with soluble phosphate gave much better early growth than Nitrophosphate. On very many soils cereals require phosphate only to ensure quick establishment, and for this purpose water-soluble phosphates are much to be preferred.

In extending earlier work on methods of placement for PK and NPK fertilizers, experiments were made to test individual fertilizers. On the average of seven experiments on potatoes, ammonium sulphate at a light rate (0·5 cwt. N per acre) was better placed, whilst double this amount was better broadcast. Placing potassium sulphate (3 cwt. per acre) gave slightly higher yields than broadcasting in five of seven experiments.

There was no worth-while advantage from splitting the nitrogen dressing, applying half at planting and half in the summer, over giving all of it at planting. In another series of experiments additional nitrogen as a top dressing gave only trivial increases in yield, even in areas where potatoes are regarded as maturing too early in the autumn.

In further experiments on horticultural crops placed fertilizers gave better results than broadcast fertilizers on lettuce, cabbage, beetroot, broad beans and runner beans. The benefit showed particularly well in the first cuttings of lettuce, French or runner beans and cabbage.

Much of the work on fertilizer placement has now reached the stage at which it should be extended to other areas not easily reached from Rothamsted. A useful beginning has been made in this direction in the Eastern Province of the National Agricultural Advisory Service in trials on threshed peas and also on peas picked green for market, canning, or freezing.

Experiments on several crops have shown the advantage of placing moderate amounts of PK fertilizers near the seed. In a recent experiment on lucerne a " starter-dose " of superphosphate placed directly beneath the seed improved establishment and early growth. Many experiments on old arable soils have shown only small responses to normal dressings of phosphate fertilizers, and considerable economy could often be made by broadcasting a fertilizer rich in nitrogen and potassium and placing a small amount of water-

soluble phosphate near the seed to promote early growth and to act as an insurance against an unsuspected deficiency of soil phosphate. Heavy manuring of potatoes and other more responsive crops often supplies unnecessarily large amounts of phosphate, and there is now a need for an additional National Compound Fertilizer with high N, low P and high K or even for an NK fertilizer. For cereals P and K should always be applied by combine-drill, with nitrogen broadcast at rates limited only by the risk of lodging. Kale and similar forage crops require only moderate quantities of phosphorus and potassium, which could be applied as a "starter-dose" close beneath the seed, with nitrogen broadcast at seeding time or later, at much heavier rates than are commonly given.

Long-term effects of fertilizer treatments

The conclusions drawn in the preceding paragraphs are based on single-year experiments. A number of the experiments were continued for a second or third year, but the residual benefits were generally small, and the comparisons of alternative materials after the first season were of low precision. Since the residual effects are generally small, there is little point in attaching much importance to them in comparing alternative fertilizers and in considering many other problems in practical manuring, with one important exception. There is no doubt that long-continued manuring at high rates builds up substantial reserves. Many farmers would justify their continued heavy use of phosphorus and potassium fertilizers as a long-term investment.

An extreme example of long-term residual effects is afforded by ten plots on the Exhaustion Land of Hoos Field, some of which received PK fertilizers or farmyard manure annually between 1856 and 1901 with none since. Nitrogen fertilizers have been applied to annual barley crops on these plots during the last dozen years, and the plots with manurial residues have given roughly twice the yields on the plots without. R. G. Warren, in continuing his analyses of soils and crops from the older Rothamsted experiments, has obtained results summarized in Table 3.

TABLE 3

Hoos Field Exhaustion Land

Plots	Annual manuring 1856–1901	Mean yields, P and K contents of barley in cwt. per acre per annum, 1949–51				Exchangeable K in soil, 1951, mg. K per 100 g.
		Dry grain	Dry straw	P	K	
1, 2, 5, 6	no P, no K	10·1	11·6	0·033	0·137	6·1
9	P (with K to 1875)	19·7	19·0	0·071	0·226	7·0
7, 8, 10	P, K	21·1	20·7	0·077	0·337	11·2
3, 4	F. Y. M	21·3	22·0	0·082	0·289	9·3

The plots with PK or farmyard manure last century gave crops with over twice as much phosphorus and potassium as those not receiving these manures. It is not easy to decide whether the P and K act independently or whether the large crops grown by the P residues are able to explore the soil more thoroughly for K. It was shown in the 1950 Report that the readily soluble P in the soil

was higher on the plots with P residues, and the difference has been brought out vividly in several recent pot experiments on soils from these plots. Although the residues of P and K are sufficient to double the yields of barley, it may be noted that the amounts of these elements recovered each year in the crops represent only very small fractions (around 0·5 per cent) of the total amounts applied to the plots last century. This experiment gives a good example of the long duration of manurial residues and the very low rates of recovery. Although the exchangeable potassium contents reflect past treatments, they account for only a small part of the residues, the bulk of which must remain in other, as yet, ill-defined forms.

W. E. Chambers has recently published (12, 13) two parts of an investigation on the soils and crops of the Broadbalk wheat experiment. One paper follows changes over long periods, and the other through a single season. On plots which had received no added potassium, the crops over eighty years extracted three or four times as much potassium as was found in the exchangeable form. Large changes in the amounts of potassium added to or removed from the soil were associated with only small changes in the amounts of potassium extractable by a neutral salt solution or by dilute acids. It was also shown that sodium and magnesium sulphates increased the uptake of potassium by the crops, presumably by liberating potassium from some non-exchangeable form. It would appear from investigations on the Hoos Exhaustion Land and on Broadbalk that the amounts of exchangeable or readily soluble potassium are only loosely and indirectly related to the amounts likely to be taken up by crops, though they provide convenient empirical methods for comparing soils.

Radiotracers in soil and fertilizer research

G. E. G. Mattingly carried out pot experiments using labelled monocalcium phosphate as a tracer. One series paralleled the series of field experiments already summarized in Table 1, but included five soils, four neutral and one acid. It is convenient to express the results as "A values" (i.e., estimates of amounts of soil phosphorus bearing the same ratios to the added labelled phosphates as are found for the soil and fertilizer phosphorus in plant samples). The purpose of several of the pot and field experiments was to see how far the estimated "A values" were altered by adding other unlabelled phosphorus fertilizers to the soils. Table 4 shows satisfactory agreement between the changes in "A values" and the amounts of unlabelled fertilizer added. (P labelled with 10 μ C activity was added at the rate of 2 mg. P per pot with

TABLE 4

Pot experiment on ryegrass

P in mg. per pot added as unlabelled fertilizer	Increase in "A values", mg. P per pot	
	Mean of four neutral soils	One acid soil
5·0 as superphosphate	5·3	6·6
10·0 as superphosphate	10·9	11·2
7·5 as dicalcium phosphate	8·3	8·4
7·5 as silicophosphate	7·0	8·2
7·5 as Gafsa rock phosphate	−0·3	10·6

400 g. soil. The estimates are for the second cut of perennial ryegrass.)

The estimates made from plant analyses agreed fairly well with the amounts of fertilizer added, with the expected exception that Gafsa mineral phosphate was inactive on the neutral soils. Experiments of this kind can be used to provide estimates of the relative availabilities of phosphate fertilizers, even where the yield responses are small.

A second pot experiment tested soils from the Hoos Four-course experiment on the residual effects of superphosphate and Gafsa mineral phosphate over five-year periods. The results are not fully worked out. They showed the expected differences between the two forms of fertilizer, and that increasing the specific activity of the labelled phosphorus five-fold reduced the uptake of fertilizer phosphorus by about 10 per cent, but did not affect the yields or uptake of soil phosphorus.

G. E. G. Mattingly with G. W. Cooke also carried out several field experiments. In one series (Table 5) labelled phosphorus fertilizers containing 0·1 cwt. P_2O_5 per acre were placed below the seed on plots which provided contrasts between various unlabelled fertilizers applied broadcast.

TABLE 5

Field experiments on labelled fertilizers

Unlabelled fertilizer broadcast, cwt. P_2O_5 per acre	Increase in "A values", cwt. P_2O_5 per acre		
	Barley straw		Fodder-beet tops
	Highfield	Sawyers	Highfield
0·3 as superphosphate ..	0·12	0·03	0·32
0·6 as superphosphate ..	0·35	0·31	0·70
0·45 as dicalcium phosphate ..	0·27	0·14	0·44
0·45 Gafsa mineral phosphate	−0·04	−0·04	0·25

The barley straw gave increase in "A values" markedly below those expected from the amounts of phosphate fertilizers broadcast, but the agreement was satisfactory for fodder beet in Highfield.

In a second kind of experiment on barley with 0·1 cwt. P_2O_5 per acre of labelled superphosphate placed near the seed, broadcasting 0·2 cwt. P_2O_5 per acre as unlabelled superphosphate increased the A value by about 0·04 cwt. P_2O_5 per acre. With 0·2 cwt. P_2O_5 per acre of labelled superphosphate broadcast, the placing of 0·1 cwt. P_2O_5 per acre as unlabelled superphosphate increased the A value by 0·30 cwt. P_2O_5 per acre. This experiment indicates by measurements from both directions that the placed fertilizer was from three to five times as effective as an equal weight of broadcast fertilizer, but the results are provisional, as the main purpose of the experiment was to test and develop a technique for field experiments using labelled fertilizers.

O. Talibudeen used some of the soils from the above pot and field experiments for evaluating the rate and extent of isotopic exchange of phosphorus under laboratory conditions.

Solubility tests on Gafsa rock phosphate

F. S. C. P. Kalpagé studied the approximate equilibria established between excess finely ground Gafsa phosphate rock and various

dilute acids and chelating agents. When increasing amounts of Gafsa phosphate rock (in excess of those required for full solution) are added to fixed quantities of dilute hydrochloric acid, the amount of carbon dioxide liberated steadily increases and the amount of phosphate in solution decreases. The apparent solubility of phosphate rock can be increased at will to any value by selecting the ratio of acid to rock. Extrapolation indicates that about 20 per cent of the total calcium carbonate present is dissolved independently of the rest. If this is regarded as " free calcium carbonate ", it might be supposed that the attack on the remaining complex is arrested when it becomes coated with dicalcium phosphate. An alternative interpretation is that the phosphoric acid and monocalcium phosphate formed by the initial attack on the rock react with the " free carbonate " exposed by the undissolved complex and are precipitated as dicalcium phosphate. Attempts are being made to distinguish between these two views. The final equilibria do not agree sufficiently well with the solubility product for dicalcium phosphate to support the view that the solutions are saturated with this substance. O. Talibudeen found that from 4 to 6 per cent of the phosphorus in the undissolved residue equilibrated with added radio-phosphorus. This is of the same order as would be expected if dissolved phosphate was precipitated in an active form by reaction with " free calcium carbonate ". F. S. C. P. Kalpagé also studied the equilibria with citric acid, alone and partially neutralized, and with sodium versenate, which around pH 7·5 extracts more Ca and P from excess phosphate rock than 0·1*N*.-HCl does at pH 3·0.

Nutrition problems in forest nurseries

Investigations were continued in conjunction with the Research Branch of the Forestry Commission, B. Benzian being in charge of the field work, and R. G. Warren, assisted by H. A. Smith and J. E. A. Ogborn, of the analytical work. Members of the Soil Microbiology and Nematology Departments investigated special aspects of some of the field experiments. Summaries are published in the Forestry Commission's annual *Reports on Forest Research* (20).

Most of the experiments in six nurseries are planned to run for several years with repeated annual crops of Sitka spruce or other conifer seedlings or transplants. As seasonal fluctuations are inevitably large, summaries are postponed until a series of experiments is completed. In 1953 two large rotation experiments at Sugar Hill Nursery, Wareham, and Kennington Nursery, Oxford, completed their preliminary years to give all phases of a three-course rotation testing fallow, various green crops, seedlings and transplants in the second phase and seedlings in the third phase, with additional comparisons between compost and fertilizers, repeated every year. There are supplementary experiments on manuring continuous seedbeds and continuous transplant beds and on testing as transplants seedlings raised in the second and third phases of the main experiment. The sites had not before been used for nurseries and, as special precautions have been taken to isolate the plots, it is hoped that the experiment may produce evidence on the vexed question of whether composts and other

methods of supplying organic matter are essential for maintaining productivity over long periods.

During the last few seasons new plots on a very acid sandy soil at Sugar Hill Nursery have shown a characteristic needle tip-burn on many of the plants with fertilizers but on very few of those with a standardized compost made from bracken and hop waste. The symptoms have not been recognized in any other nursery, and no explanation can yet be offered, apart from the possibilities of lack of calcium or some minor element.

In 1953 early sowing and a moist season allowed very good growth in most experiments, with marked responses to major nutrients, especially nitrogen. Deficiency symptoms showed earlier, but seemed more complicated than usual. Sitka spruce seedlings provide sensitive material for studying the interrelationships of N, K and Mg, and the effects of these and other elements are being tested in plots as well as in the field.

TABLE 6

One-year seedlings of Sitka spruce 1953

	Mean height in inches		
	Four neutral or moderately acid soils		Two very acid soils
	Without formalin	With formalin	Without formalin
No nitrogen	0·9	1·6	1·6
Calcium nitrate	1·2	2·3	2·6
" Nitro-Chalk "	1·4	2·5	2·5
Ammonium sulphate ..	1·6	2·3	2·4
Formalized casein ..	1·6	2·6	2·9

In past years some of the benefits from formalin treatment, especially in the older nurseries and on neutral soils, have been ascribed in part to the inhibition of nitrification and the consequent accumulation of ammonia. Additional evidence on this point was obtained in 1953 from experiments at six nurseries testing four alternative forms of nitrogen fertilizer supplying 9 g. N per square yard: formalized casein applied a month before sowing and three inorganic nitrogen fertilizers applied to two summer top-dressings. Table 6 shows mean heights of one-year Sitka spruce seedlings in experiments with treatments in both 1952 and 1953. The data for four nurseries on neutral and moderately acid soils are given for plots with and without previous treatment with formalin. Where no formalin was given, growth was poor throughout, particularly on plots with calcium nitrate; the superiority of ammonium sulphate over calcium nitrate was significant in three of the four experiments, and " Nitro-Chalk " gave intermediate results in all four. Formalin greatly increased growth for all treatments, and at the poor established nurseries gave crops resembling those grown in very acid newer nurseries. Further, on formalin plots at old nurseries and on plots without formalin on very acid soils there were only small differences between the three kinds of inorganic fertilizer. The superiority in 1953 of the slowly acting organic fertilizer applied in the seedbeds may be due to its supplying nitrogen in a wet season before the inorganic fertilizers were given as top-dressings.

The series of experiments added support to the view that conifers profit from receiving their nitrogen as ammonia.

In several experiments chlorpicrin injected in January or February 1953 gave improvements similar to those from formalin applied as a drench. Series A in Table 7 shows that earlier application was sometimes better for formalin, but that the time of application had no effect for chlorpicrin.

TABLE 7

One-year seedlings of Sitka spruce 1953

	Mean heights in inches			Eelworms per plant
	Kennington K 68	Ampthill Am 30	Ringwood R 59	Ringwood R 59
Series A				
Untreated	1·8	1·8	1·4	100
Chlorpicrin—January	2·5	2·9	2·7	2
Chlorpicrin—February	2·5	2·9	2·8	4
Formalin—January ..	3·1	2·7	2·8	17
Formalin—February ..	2·5	2·7	2·0	89
S.E.	±0·10	±0·15	±0·12	—
	K 69	Am 31	R 58	R 58
Series B (January treatments)				
Untreated	1·7	1·8	1·3	156
Paraformaldehyde ..	2·1	1·9	1·5	111
DD	2·1	2·7	2·8	4
Ethylene dibromide ..	2·2	2·5	2·8	2
Formalin	3·1	2·7	2·9	8
S.E.	±0·08	±0·09	±0·07	—

In Series B ethylene dibromide and DD applied in January gave very good results at two of the nurseries but much poorer ones at the third (Kennington). At all three nurseries paraformaldehyde gave little improvement in 1953.

J. B. Goodey continued his examination of plants from several experiments in the Ringwood nursery, making counts of the numbers of the nematode *Hoplolaimus uniformis* in seedlings and transplants. At this nursery January applications of formalin, chlorpicrin, ethylene dibromide and DD greatly increased growth and markedly reduced infestation with nematodes, paraformaldehyde in January and formalin in February being much less effective on growth and against nematodes. Similar results were obtained in other seedbed experiments at Ringwood. Formalin treatment of transplants beds at Ringwood reduced the mean numbers of eelworm from 1,680 to 120 per plant. Although this is presumptive evidence that part of the benefits from fumigants is through control of eelworms, it may be noted that in the Ampthill nursery, where plant and soil examinations have revealed very few eelworms, the effects of various fumigants on plant growth were generally similar to those at Ringwood. The Ringwood eelworm data thus add one more class of organisms to the lengthy list already known to be affected by soil fumigation in our forest nursery experiments.

Six species of conifers showed closely similar responses to fumigation with formalin and chlorpicrin and also to other manurial and remedial treatments. The 1953 plots and stockbeds of Sitka spruce in each of the older nurseries (now no longer used for raising

conifer seedlings) gave, after formalin treatment, outturns of usable seedlings approaching those from the best new nurseries in the country. If techniques for soil fumigation can be interpreted, standardized and mechanized they may prove to have applications not only in forest nurseries but in some intensive branches of horticulture in the open as well as under glass.

The nature of soil organic matter (J. M. Bremner)

Previous work on the estimation and decomposition of amino sugars in soil and on the identification of hydroxylamine and hydrazine by paper chromatography was completed and prepared for publication.

Earlier work on the chemical nature of the nitrogen in the humic (i.e., acid-insoluble) fraction of soil extracts was extended by comparing the properties of humic fractions isolated from 0·5*N*-sodium hydroxide and 0·1*N*-sodium pyrophosphate (pH 7·0) extracts of mineral and organic soils. This investigation showed that alkali- and pyrophosphate-extracted humic acids differed markedly in nitrogen content, nitrogen distribution and other properties. For example, the proportion of the total nitrogen liberated in the form of amino-acids by acid hydrolysis of the alkali-extracted humic acids (31–48 per cent) was considerably greater than that liberated by hydrolysis of the pyrophosphate-extracted acids (20–35 per cent). Estimation of the amino-sugar contents of the preparations by an alkaline decomposition technique showed that only 3–8 per cent of their total nitrogen was in the form of amino-sugars. No marked differences in the amino-acid compositions of the alkali- and pyrophosphate-extracted humic acids could be detected by paper chromatographic examination of their acid hydrolysates. The nitrogen in both types of humic acids was practically non-dialysable through Cellophane.

Previous work on the effect of nitrous acid on humic acid preparations has been extended by a detailed investigation of the behaviour of various alkali- and pyrophosphate-extracted humic acids under the conditions used in the Van Slyke nitrous acid method of estimating amino-nitrogen. The results showed that 10–20 per cent of the nitrogen in the humic preparations examined could be accounted for as free amino-nitrogen by this method using a reaction period of 15 minutes. The amount of gas evolved under the conditions of the Van Slyke method was found to increase steadily with time of reaction. The reaction was not affected by light, and the results were not significantly different when the preparations were dialysed against distilled water or extracted thoroughly with ether, alcohol, benzene or dilute acid before analysis. The mechanism of the reaction between humic acid and nitrous acid is still obscure, but analysis of the products has shown that the reaction leads to an increase in the nitrogen content. Tests with straw and wood lignins showed that treatment of lignin with cold nitrous acid also led to an increase in the nitrogen content and that methoxyl groups were destroyed in the reaction. Whatever the nature of the reaction between humic acid and nitrous acid, it does not appear to involve free amino-groups, since no free amino-groups could be detected when the preparations were examined by the fluorodinitrobenzene technique developed by Sanger.

Previous work on nitrogen transformations during the biological decomposition of straw composted with ammonium carbonate has been completed, and a paper giving the results is being prepared for publication. The transformations were studied by following changes in the amounts of inorganic and organic nitrogen present and in the amounts of ammonia-, volatile base-α-amino- and amino-sugar-nitrogen liberated by acid hydrolysis. Changes in the amino-acid composition of the composts were also studied by paper chromatographic examination of their acid hydrolysates. The results showed that synthesis of organic nitrogen during the biological decomposition of straw composted with ammonium carbonate is not accompanied by any gross change in the distribution of the organic nitrogen in the compost. A large fraction of the organic nitrogen synthesized is in the form of protein; a smaller fraction is in the form of amino-sugars. The amino-acid compositions of acid hydrolysates of the rotted and unrotted straws were not greatly different. The rotted, but not the unrotted, straw hydrolysates contained β-alanine and a substance provisionally identified as αε-diaminopimelic acid. Tests with an oat straw compost containing 3·94 per cent nitrogen showed that it nitrified extremely slowly when incubated with soil under conditions known to produce rapid nitrification of casein and ammonium sulphate.

The search for methods of fractionating and characterizing inositol phosphates has been continued, and promising results have been obtained using the method of paper electrophoresis. An attempt is now being made to use this technique to identify inositol phosphates in soil.

The decomposition of organic materials in soil (K. Shaw)

The rates of decomposition of various commercial nitrogenous materials and of nitrogenous materials prepared in the laboratory have been studied by estimating the mineral nitrogen (ammonia + nitrate nitrogen) produced on incubation of the samples with soil under standard conditions. A product containing 11·7 per cent *N* prepared by the nitration of sawdust was found to produce only about 10 p.p.m. of mineral nitrogen in eighty days. Two commercial nitrogenous materials, hoof and casein, were formalized in the laboratory. The formalization had only a temporary depressing effect on the rate of mineralization of the nitrogen, and after seventy days the production of mineral nitrogen was approximately equal in the formalized and normal products. A material prepared by the deamination of casein decomposed at nearly the same rate as the untreated protein.

Work was started on the formation and decomposition of " mat " on old permanent pasture, using initially samples of " mat " separated from the underlying mineral soil on some of the Park Grass Plots (plots 1, 4_2 and 11_1). A preliminary fractionation of this organic material shows decreasing amounts of cellulose and hemicelluloses and an increasing amount of lignin on passing down through the " mat ". The rate of decomposition of the material when mixed with its underlying mineral soil, with two added levels of nitrogen and calcium, is being followed by measuring the carbon dioxide and mineral nitrogen produced during incubation. The results so far obtained with samples from the unlimed section of

plot 1, which has received nitrogen annually for many years, indicate that added nitrogen has no effect on the rate of production of carbon dioxide from the " mat " material at any level of calcium.

The simultaneous determination of ammonia and nitrate nitrogen in Olsen extracts of soils by reduction with reduced iron in acid solution at room temperature was found to be unsatisfactory. Better results were obtained when titanous sulphate was used as a reducing agent in place of the reduced iron, and the ammonia formed estimated by distillation with magnesium oxide in Conway Units at room temperature, but the recovery of added nitrate was still incomplete. However, almost complete recovery of nitrate nitrogen as ammonia was obtained by carrying out the reduction with titanous sulphate and distilling with magnesium oxide in a larger plastic modification of the Conway Unit which permitted more satisfactory mixing of the contents of the outer chamber.

Soil Manganese (S. G. Heintze)

In a group of soils, mainly alkaline and with high organic matter, the occurrence of manganese deficiency symptoms in crops was associated with low values for several variables : total manganese, the absolute quantities and the fractions of the total manganese extracted by neutral ammonium acetate with hydroquinone or sodium hydrosulphite, calcium nitrate after reduction with hydroquinone, sodium pyrophosphate at pH 9·5. The mean of the two methods based on hydroquinone was somewhat better than either method separately. No single fraction of the soil manganese has been found to give an adequate estimate of availability to plants, but any of the above methods would merit further attention where it is necessary to classify soils in relation to field observations.

Neutral solutions of pyrophosphate do not extract much manganese, even in the presence of hydroquinone. Alkaline pyrophosphate removes much larger quantities, but dissolves large amounts of organic matter, which may reduce manganese in high states of oxidation. Sodium versenate behaves in the same way as alkaline pyrophosphate; solutions of sodium calcium versenate at pH 9·0 give only light-coloured extracts but remove more manganese from organic soils than neutral pyrophosphate. Neutral solutions of sodium calcium versenate dissolve less manganese than neutral pyrophosphate solutions, but the amounts of manganese dissolved by sodium calcium versenate are greatly increased by the presence of hydroquinone. These findings are consistent with, but do not establish, the view that in organic soils a considerable amount of the manganese present is held in high-valency forms by the organic matter.

General

Early in 1953 E. M. Crowther made an eleven weeks' tour in the Sudan and East Africa at the request of the Sudan Government, the Empire Cotton Growing Corporation and the Colonial Office Advisory Committee on Agricultural Research. In addition to visiting several research institutes and experiment farms, he attended a Specialist Conference on Fertilizers at the East African Agriculture and Forestry Research Organization and the Annual Research Meeting of the Sudan Ministry of Agriculture. J. M. Bremner

attended the 17th Conference and 13th Congress (Physical Chemistry, Wood and Paper Chemistry) of the International Union of Pure and Applied Chemistry at Stockholm.

J. C. Wilcox, of the National Agricultural Advisory Service, J. Bolton, of the Colonial Agricultural Research Service, and A. Y. Kordofani, of the Sudan Ministry of Agriculture, were seconded to the Department for work on field experiments. P. W. W. Daborn of the Forestry Commission took the place of C. P. Kirkland on secondment for forest nursery work. A. E. Johnston was appointed for analytical work.

PEDOLOGY DEPARTMENT

A. Muir

At the invitation of the Colonial Office and the Government of Nyasaland Dr. Muir took charge of a soil survey of the Shire Valley area which was required in connection with a large development project. Prof. J. L. White of Purdue University has come for a year to work in the department of clay mineralogy. Mr. R. Greene-Kelly has been awarded the degree of Ph.D. by London University for a study of the sorption of polar molecules by clay minerals, and Mr. J. Gasser the degree of M.Sc. for his work on the behaviour of iron and other phosphates during the fermentation of plant materials under anaerobic conditions.

Soil Mineralogy

Kenya

During the year work has continued on the mineralogy of the "gilgai soils" of the Athi Plains, near Nairobi (see 1952 Report), and it has now been shown that these soils cannot be regarded as entirely residual from the underlying volcanic rocks (phonolites, phonolitic trachytes, etc.). This is indicated by the presence of such minerals as sillimanite, garnet, staurolite and kyanite, which are the characteristic minerals of metamorphic rocks of gneissose type, and which occur at all levels in the soil profile above that of the weathered rocks. It is very difficult, however, to make an estimate of the amount of contamination. It may well be that the soils are in the main derived from the underlying volcanic rocks, and have had a "wash" of material of foreign origin deposited on top, which has been incorporated in the soil due to the "churning-up" action resulting from their shrinking and cracking properties. (I. Stephen.)

Nyasaland

A study of the mineralogical composition of a suite of soils from the lower Shire River area has been commenced with the object of defining the types of soil parent materials, which do not appear to be all of alluvial origin. (I. Stephen.)

Clay Mineralogy

Soil morphology and mineralogy

It has been shown (27) that lepidocrocite of pedological origin is of widespread occurrence in British soils and that its appearance is associated with gleying. Work has been done on three gleyed soils from Lancashire in a preliminary exploration of the relation of morphology to mineralogy. The soils were those studied by Bloomfield (1952, *J. Soil Sci.*, **3**, 167). Separates of closely associated brown and grey soil were used, and the clay fractions were examined by X-ray diffraction. This limited investigation suggested that the hydrated ferric oxides goethite and lepidocrocite are the pigments

of the brown mottles of gleyed soils and that rate of oxidation decides which is formed, slow oxidation favouring the formation of lepidocrocite. It also appears that the alumino-silicate clay minerals of associated brown and grey soil are identical in kind and relative amount, but variations in amount occur between different soil horizons and different profiles.

A more detailed study is being made of another gleyed profile from Lancashire in an effort to relate detailed field morphology to laboratory data. For this purpose the semi-micro method for the preparation of clays (28) was devised, and in addition an approximate method of mechanical analysis for similar small amounts of soil has given satisfactory results. (G. Brown.)

Palygorskite

The study of an occurrence of the clay mineral palygorskite (attapulgite) has been completed and will be published shortly. The palygorskite occurs with montmorillonite in a decomposed syenite. The exchange complex of the altered rock, in agreement with the occurrence of magnesium-bearing clay minerals, is saturated dominantly with magnesium ions, and it seems clear that the alteration involved the introduction of magnesium solutions from elsewhere than the parent rock. In the field the juxtaposition of highly decomposed and essentially unweathered syenite suggests that the alteration of the rock is not due to atmospheric weathering, but to the action of hydrothermal solutions, which have permeated the rock mass.

Samples of other clays, known as pilolite (Heddle, 1879, *Min. Mag.*, **2**, 206), " mountain leather " and " mountain cork " have also been examined, and these have been found to give X-ray diagrams identical with that of the Shetland palygorskite. (I. Stephen.)

Dickite and kaolinite

In collaboration with Dr. F. Smithson, University College of North Wales, examination of samples of a kaolin from British sandstones has been made in addition to those reported in *Nature* (31). In the majority of cases it has been possible to identify the mineral even when it is contaminated. The additional results are largely in accord with those published, viz., that where alteration of other minerals in the sandstone seems to have occurred, well-formed plates of the kaolin are present and have been shown to be dickite. Where no alteration is suspected well-formed plates are absent and the mineral is kaolinite. (G. Brown.)

New clay minerals

A previously unreported vermiculin, i.e., a member of the vermiculite group (cf. kaolin, kaolinite), has been encountered and shown to be the dioctahedral analogue of vermiculite. In addition, a mineral which may be analogous to the ill-defined material which some American workers call mica-intermediate has been recognized, and diagnostic criteria have been established. Both minerals occur in mixtures with other clay minerals in soil clays and pure samples have not yet been obtained.

In previous years reference has been made to an unidentified 14 Å. mineral which resembled vermiculite in collapsing to give a 10 Å. spacing after heating to 300° C., but which did not collapse to 10–11 Å. spacing after boiling for short periods with ammonium salt solutions. It has been shown that prolonged treatment, 10-hour boiling with ammonium or potassium salt solutions, collapses the mineral, giving a 10–11 Å. spacing, and that the collapse can be reversed by treatment with Mg-salt solutions. It is thought that these experiments show that the mineral is a vermiculin with a difficultly exchangeable cation, and it is suggested that this cation may be partly organic. In addition, the mineral has an (060) spacing of 1·50 Å., and hence is probably the dioctahedral analogue of vermiculite.

The name " degrading illite " has been given provisionally to a material which gives a band with a high angle edge at 10 Å. and which " tails off " towards lower angles. In some cases the low angle edge of the band is at 14 Å., but generally the band is not so broad. The width of the band depends in part on the exchangeable cation. The band disappears after treatment of the clay with glycerol and, if vermiculin is absent, a sharp line at 14 Å. appears. It has not yet been possible to decide whether all the layers responsible for the band expand to 14 Å. with glycerol treatment, or whether the band is resolved into lines at 10 Å. and 14 Å., as the mineral is always associated with much illite with a strong line at 10 Å. It is hoped that comparative photometry will lead to a decision on this point. When the clay is heated to 300° C. for 12 hours the band disappears along with the 14 Å. vermiculin line, and the intensity of the 10 Å. is enhanced by the collapse. (G. Brown.)

Lancashire soil parent materials

Further work has been done on these to explore the usefulness of clay mineralogy for differentiating surface deposits, commonly known as drifts, which form the parent materials of many British soils. Previously C. J. Tapp, of the Soil Survey of England and Wales, had been able to differentiate the Carboniferous and Triassic drifts according to the rate at which they release potassium to strong acids, the latter having a higher rate of potassium release than the former, and his work suggested that the cause of the difference lay in the clay fractions. Careful examination of the clays from a number of soils shows that their mineralogy is never simple. The clay minerals found are kaolin, illite, " degrading illite ", vermiculin and chlorite. All are often present, and no clay has been found with fewer than three of them. In addition, all clays derived from Triassic deposits contain a small amount of a mineral similar to that from the Keuper Marl which Honeyborne (*Clay Minerals Bulletin* **1**, 150) described. As well as the clay minerals, lepidocrocite, goethite, quartz and anatase are common constituents, the last two in small amounts.

An attempt is being made to unravel these complex suites, giving particular attention to the hydrous micas, by careful photometry of X-ray patterns of clays which have had different diagnostic treatments. A measure of success is promised not only in correlating and in a few cases correcting field classification of drifts but also in relating the potassium release figures to the illite content of the

clays. In addition, our knowledge of the clay mineralogy of these drifts has been increased. (G. Brown.)

Broadbalk soils

A start has been made in a detailed study of the Broadbalk soils in an area including Plots 2–13 and the Wilderness. The objects of this work are two-fold. First, to correlate differences in clay properties with comparatively recent changes in vegetational cover and fertilizer treatment. Secondly, to assess the relative value of different methods of studying the clay fraction. The results already obtained have shown that the differences between the surface soils of the arable plots and those of the Wilderness are superficial, and are not reflected by changes in the clay mineral content. The exchange capacities vary, but this has been satisfactorily correlated with the amounts of organic matter present in the soil. Profiles examined in the Wilderness show poor development; although there is an increase of clay content going down the profile, little or no change in clay composition occurs. This is explained by the results of detailed study of the clay fraction of the C horizon. Here the composition of the clay is nearly independent of size fraction, and it can be concluded that these soil clays would not be altered in composition during the process of being washed down the profile. These studies have also emphasized the ease with which the Broadbalk soil clay is deflocculated in the absence of organic matter. Considerable improvement in stability was observed with surface soils from the Wilderness, which are higher in organic matter than those from the arable plots. The total exchange capacity of different size fractions from the C horizon increases with decreasing particle size, but the changes are much less than might be expected if the exchange capacity is proportional to surface area. The composition of the clay fraction has been found to be illite, kaolinite, with small quantities of chlorite and goethite. The quantitative estimation of the composition of the clay fraction has not proved feasible by X-ray methods, but differential thermal analysis has been successfully employed to estimate the amount of kaolinite. A value of 20 per cent, nearly independent of particle size, was found. This figure does not appear to be compatible with the results of silicate analysis of the clay fractions if it is assumed that the clay consists predominantly of kaolinite and illite. Much higher values were obtained for the sesquioxides than would be expected from the mineralogical composition. The occurrence of amorphous aluminium and iron oxide appears probable. (R. Greene-Kelly.)

In addition to the clays reported above, samples from Northumberland, Yorkshire, Cambridgeshire, Bedfordshire, Buckinghamshire, Hertfordshire, Sudan, Gold Coast, Kenya and Persia have been examined. (G. Brown.)

Potash fixation

A number of surface soils from Eire was examined in an attempt to relate clay mineralogy to potash fixation which had been established by field experiments. It was found that " degrading illite " was the only distinguishing clay mineral between soils which fixed potassium and those which did not. No potassium fixation could be

attributed to illite or vermiculin. It has been possible to foretell which soils are potassium fixers by X-ray-diffraction tests. However, this work has been done on a limited number of soils, and it is hoped to extend it. (G. Brown.)

Ion exchange studies

The dioctahedral montmorillonite minerals can now be identified with precision by means of a diagram which relates their composition to their expanding properties after lithium saturation and heating. Over fifty montmorillonite minerals from soils and deposits have been classified by this technique. It has been concluded that dioctahedral soil montmorillonite minerals generally belong to the intermediate class where the exchange capacity originates about equally from tetrahedral and octahedral substitution. A study of montmorillonite minerals derived from different parent materials has emphasized the need for a more exact knowledge of the relation between the magnesium content of the parent material and the type of clay mineral derived from it. Although it is generally true that under basic conditions magnesium-bearing parent materials give rise to montmorillonite whereas those low in magnesium give beidellite, several exceptions to this rule have been found.

The exchange capacity of lithium-saturated montmorillonite after drying has been found to give reliable values for the external surface area of the crystallites. This method is superior to gas-adsorption methods for studying the micro-structure of montmorillonite aggregates. The results, using this new method, of a study of the effect of the method of preparation of the montmorillonite on its external area has shown that, in contradiction to what was previously believed, the external surface is unaltered by different methods of preparation, despite the fact that the macro properties of the mineral are very different. The same technique has been used to study the variation of external area between montmorillonites of different morphology as revealed by the electron microscope. Surprisingly little variation has been found.

The distribution of exchange cations in the mixed lithium–sodium montmorillonite system has been investigated using the lithium-fixation method. If the lithium ions are distributed uniformly in the mixed systems, their fixation would lead to the trapping of sodium ions. If there is no miscibility the availability of the sodium ions should be unaffected by lithium fixation. In the case of Redhill montmorillonite it has been concluded that only limited miscibility occurs between the two cations.

The effect of dehydration on the availability of exchange cations on kaolin minerals has received detailed study. It has been found that after drying only lithium ions are fixed by kaolin minerals, and in contrast to montmorillonite the exchange capacity is hardly changed, structural cation exchange having taken place. This interesting effect is being further studied. (R. Greene-Kelly.)

Adsorption on clay minerals

The X-ray work on the montmorillonite complexes with simple organic molecules has been considerably extended. About a

hundred different compounds have been investigated, and in practically all cases it has been possible to interpret the results in terms of the shape and the orientation of the sorbed molecule. The techniques used for this work have been applied to the problem of the stereoisomerism of piperidine and its derivatives. Although the energy of interaction between organic molecules and montmorillonite can only be roughly estimated by X-ray methods, it is clear from the results obtained that strong interaction is more likely to occur if the organic molecule is capable of electron donation to the clay mineral. This tendency emphasizes the importance of organically combined nitrogen in promoting strong interactions between clays and soil organic matter. (R. Greene-Kelly.)

Techniques and methods

In addition to techniques previously mentioned, exploratory work has been done in the use of X-ray diffraction to establish orientation in sedimentary deposits such as lacustrine clays, and the method seems satisfactory.

The Wiessenberg goniometer has been modified for clay mineral work, and its use for the determination of orientation in oriented aggregates, which is required for quantitative clay mineral analysis, is being explored. (G. Brown,)

Powder camera

An improved form of our 9-cm. powder camera has been designed, and one of these cameras has been made for us. This camera has adjustable tantalum slits, adjustable screening plates and a screw adjustment for the film-locating peg. The specimen holder carries a pointer moving over a gradual scale of angles. The specimen can be rotated or oscillated by means of an external motor, coupled to the camera by a flexible drive. (D. M. C. MacEwan.)

Centrifuge separation of clays

A small-scale method for fractionating clays according to grain size, based on Marshall's two-layer method, has been in use here for some time (see ref. 34, Report for 1949). Although the method is useful, it has been found to be subject to certain defects, due to " streamer " formation, and it is being re-examined to see if it can be improved, by using a graded viscosity distribution in the centrifuge tubes instead of a viscous layer (glycerol solution) sharply passing into a layer of low viscosity. (D. M. C. MacEwan.)

Gas X-ray tube

A gas X-ray tube, of our own design, has been in use here for a considerable period and, in view of the simplicity of this type of X-ray generator, we wished to study its performance with various electrode positions and sizes. For this purpose an experimental gas tube has been constructed, with removable sections, allowing various dimensions to be made. This work has shown that, in ordinary operation, a considerable proportion of the total current passes to the tube wall and not to the target, a condition which is not easily remedied. Pure aluminium is the best cathode metal found; a flat cathode with a central hole of suitable depth is found to give improvement both in focus and intensity.

This work has been mainly empirical in nature; lack of time has precluded a highly systematic approach to the problem.

It is now proposed to stabilize the conditions of operation of the tube, and use it as a source of X-rays. (G. Dibley.)

Scales for measuring X-ray photographs

Direct-reading Ångstrom scales have been made for CuKα radiation. These are very rapid in use, and much more accurate than any direct-reading scales with which we are acquainted, since they have finely-spaced divisions, and full compensation for changes in film dimensions. (D. M. C. MacEwan.)

Fourier synthesis

A rapid method of fourier synthesis is desirable, both for studies on montmorillonite and for possible future work on micas, etc. A Beevers–MacEwan type machine has therefore been obtained on loan from the Dewar Crystallographic Laboratory, Edinburgh, and a counting unit is now being made for it. One experimental counter has been assembled, using ex-R.A.F. " impulse motors ". These are very inexpensive, and will count readily at 20/sec., and probably faster. They will not count negatively: consequently separate counters are used for negative and positive counting, and a subtraction unit has been made, by which automatic subtraction is performed. The use of stepwise charging of a condenser for counting is also being experimented with; this method should be very rapid, but will not be accurate. (D. M. C. MacEwan.)

Fourier transforms

This method for analysing interlayer mixtures, mentioned in last year's report, has been further studied. A slide-rule-type scale has been made which enables the necessary calculations to be very rapidly carried out. (D. M. C. MacEwan.)

Geochemistry

Investigations are being continued into the trace element content of sedimentary rocks of the Lower Lias formation. Analyses have been carried out on samples from a boring at Northleach and from the Dorset coast, and certain correlations have been found between their contents of molybdenum, vanadium, nickel and copper. Abnormally high contents of Mo (i.e., $>$ 20 p.p.m.) have been found only in the lower zones, from *Jamesoni* downwards, and here only in the less highly calcareous strata.

The content of these elements appears, in turn, to be closely related to that of material oxidizable by the dichromate wet-oxidation method, this consisting of organic matter with more or less pyrite. The pyrite, which is presumed to be of secondary origin, has been found to contain a relatively large amount of Mo, but no detectable V, whereas the separated clay fraction contains the bulk of the V and little Mo. These findings suggest that both elements were originally laid down with the organic material, but have subsequently been differently segregated.

It has not been possible so far to separate the organic matter completely from the clay, but it is hoped that further experiment will

make it possible to demonstrate whether, in fact, these elements are directly associated with the organic matter. (H. H. Le Riche.)

The general minor-element survey of English soils has been extended, and a number of Cu- and Zn-deficient samples from Wales are being studied. The results of the study of minor-element distribution in some Lancashire soils have been published (33).

A spectrographic method for determining Sm, Yb and Eu in a mixture of rare earth oxides has been used; eleven of the sixteen rare earths are now determinable.

The problem of the estimation of niobium in rocks and soils has been approached spectrographically; using the internal standard method Nb has been estimated in pyrochlore-rich soils, but the results compare unfavourably with those obtained by the much longer chemical or absorptiometric methods.

A semi-quantitative spectrographic method for estimating Pb in twig samples has been used for twigs collected from areas where variable amounts of Pb occur in the soils. The time for each determination is 4 minutes in batches of twenty or more. The method should be of some use in geochemical prospecting. (J. R. Butler.)

Soil Chemistry

Effects of leaf extracts on soil constituents

Further work on the solution of soil sesquioxides by leaf leachates has shown that both the iron and aluminium compounds formed in this process are strongly sorbed by soil colloids. It is suggested that this process is responsible for the immobilization of the sesquioxides which leads to the formation of the B horizon in podzolized soils. The sorption is particularly pronounced in the case of the New Zealand rimu, and consequently attention has been concentrated on this species.

Although it is very difficult to achieve a strictly valid comparison of the extent of sorption from the leachate of different species, on the basis of the measurements made thus far it is possible to suggest an explanation of such anomalies between the laboratory and field observations as were mentioned in the previous report (1952, p. 57). Thus, while the kauri is a more effective podzol former than the rimu, it has been found in the laboratory that of the two, rimu leaf extracts give rise to much more extensive solution of ferric oxide. On the other hand, sorption from rimu solutions is also more pronounced, so that under field conditions the kauri would give rise to greater net loss of ferric oxide from the A horizon. The same argument may be applied in the case of such broad-leaved species as ash, which, although they apparently do not give rise to any detectable movement of sesquioxides in soils, nevertheless give appreciable solution effects in the laboratory. No doubt faunal activity under broad-leaved cover also contributes in counteracting the leaching process.

A feature of grey wooded soils which are formed under a predominantly aspen cover, is that although the A_2 horizon is leached of sesquioxides, this horizon commonly has a high percentage base saturation. This apparent paradox may be readily explained by the fact that aspen leaves have been found to contain a relatively high proportion of water-soluble calcium compounds.

Although podzolized soils, *sensu stricto*, are predominantly formed on sandy materials in which clay movement would not be apparent, cases are known in which a strong textural profile is developed, and three widespread groups of soils, the grey wooded and grey brown podzolic soils of North America, and the grey forest soils of the U.S.S.R., always show this textural profile. It has been found that at low concentrations, aqueous extracts of the leaves of several tree species are capable of deflocculating clay suspensions, which would account for the removal of clay from the A_2 horizon. At higher concentrationss of the leaf extracts a tendency towards reflocculation develops. Experiments on the bark of kauri and rimu, both of which shed their bark, have shown that weight for weight, the bark has a greater deflocculating action than the leaves, and furthermore does not appear to give rise to reflocculation at higher concentrations. Further study of these processes will, it is hoped, be of value in connection with the podzol group as a whole. (C. Bloomfield.)

Mobilization of phosphate under anaerobic conditions

The effect of anaerobically fermented plant material (dried grass) on the mobilization of phosphates of aluminium, calcium and iron and of phosphated clays has been tested. No conclusive evidence for any mobilization of either aluminium or phosphate from aluminium phosphate was obtained. With various calcium phosphates the calcium and phosphate were readily mobilized due to the lowering of the pH during fermentation. In the case of a crystalline basic ferric phosphate and a non-crystalline ferric hydroxyphosphate the fermented grass caused a mobilization of both iron and phosphate. The basic ferric phosphate exhibited re-adsorption of the phosphate, presumably by " free " iron oxide. In the case of the ferric hydroxyphosphate, particle size affected the amount mobilized.

Both kaolin and montmorillonite removed phosphate from the fermenting grass solution. With phosphated clays fermented grass mobilized phosphate previously fixed by treatment of the clays with KH_2PO_4. In the case of kaolin about half the amount fixed was released, and with montmorillonite the amount remaining fixed was about equal to the amount taken up from the fermenting solution by the untreated clay. It is thought that the adsorption of inorganic P by montmorillonite occurs mainly through amorphous sesquioxides on the surface. Kaolin may also sorb phosphate in this way and also through hydroxyl replacement on the edge aluminium atoms of the crystals.

Oxidation of extracts containing iron phosphate gave a precipitate of basic ferric phosphate with organic matter, a small but significant amount of iron and phosphorus remaining in solution. It seems that this stability of iron phosphate may account for the movement of phosphorus in association with iron within the soil profile. (J. K. R. Gasser.)

The coloration of black tropical soils

A study of some black soils from India (Regur, Kabar and Karail) suggests that their dark coloration is mainly due to their clay organic complex. Using a variety of clays, formation of similar

complexes has been studied in the laboratory under anaerobic and partially aerobic conditions. Among the factors which seem to be associated with the dark clay–humus complex are : (*a*) clays of high base exchange capacity, especially when in a dispersed state due to the presence of sodium ; (*b*) conditions favouring reduction of iron ; (*c*) acid reaction, even as low as pH 3, and (*d*) certain types of nitrogenous plant residues somewhat resistant to decomposition and usually base saturated. A comparative study of the black soils with their neighbouring red soils suggests that the organic matter of the black soils is more easily oxidizable but less easily hydrolysable. (Sant Singh.)

SOIL MICROBIOLOGY DEPARTMENT

H. G. Thornton

Miss Jane Meiklejohn returned to the department in September after spending a year in East Africa on an appointment from the Colonial Office to report on problems of soil microbiology.

P. S. Nutman left in May to take up a three-year appointment at the Commonwealth Scientific and Industrial Research Organization, Canberra.

B. N. Singh left in November 1952 to take a post at the Central Drug Research Institute, Lucknow.

Miss Hilary Purchase left in September to return to Sydney after three years work in the Department, for which she was awarded the Ph.D degree, London University.

T. I. Steenson from Canterbury Agricultural College, Christchurch, joined the department in March, and has been appointed to a post as Assistant Experimental Officer.

I. L. Stevenson from the Department of Agriculture, Ottawa, came to Rothamsted in June for a period of two years.

Miss U. de Barjac from the Pasteur Institute, Paris, paid a visit of six weeks to the department.

The work of the department has been concerned with the competition between actinomycetes and root pathogenic fungi, the influence of partial sterilization on the microflora in forest nursery beds, the decomposition of chlorinated aromatic compounds by soil bacteria and with various problems relating to the nodule bacteria of leguminous plants.

Antibiotic Production by Actinomycetes in Soil

The usefulness of actinomycetes that produce antibiotics in combating root infecting fungi is limited by the fact that the antibiotics produced by them tend to be adsorbed and rendered inactive by soil constituents, and especially by the clay fraction. It is thus important to know which actinomycete antibiotics are least affected in this way and how active these are in different types of soil. I. L. Stevenson is studying ten actinomycetes selected for activity against root disease fungi, particularly *Helminthosporium sativum*, and the influence of clay minerals, soil type and soil reaction on the production by them of antibiotics. In media, differences in reaction influenced the production of antibiotic by a few only of the actinomycetes tested. The addition of bentonite greatly reduced antibiotic activity, but kaolin had little or no effect. The addition of soil to agar media also reduced activity, but this varied with the soil type and with the species of actinomycete. Those species whose antibiotic properties in agar were least affected by the addition of soil also showed the most consistent antibiotic activity when grown in the soil itself. Their activity in soil was also affected by soil type and reaction. Four of the actinomycete strains tested were identified as *Streptomyces antibiotious*, and the antibiotic

produced in soil was extracted and gave the chemical tests for Actinomycin. Pot experiments with wheat in several sterilized soils confirmed that root rot by *Helminthosporium sativum* was significantly reduced by some of the actinomycete strains, and this reduction was in general related to the activity of the strains *in vitro*.

The Effect on Nutrient Supply on Competition between Actinomycetes and Fungi in Soil

In his study of competition between an actinomycete and the root pathogen *Fusarium culmorum*, F. A. Skinner showed that the actinomycete reduced growth of the fungus more in media that were rich than in those low in energy supply. This was the case whether antagonism was attributable to antibiotic action or to competition for some available nutrient. This effect of energy supply on competition may also be important where it is desired to introduce and establish an organism, for example one that is antagonistic to a root pathogen, in fresh soil in competition with the natural micropopulation. An investigation is therefore being made of the effects of energy supply on the establishment of organisms, including some that are antagonistic to fungal pathogens, in fresh soil and in sterilized soil to which other organisms have been added. This work is in progress.

Partial Sterilization

The survey of changes in the soil micropopulation of forest nursery plots that have been given various forms of partial sterilization has been carried out for several years, and was continued by Miss L. M. Crump during the period under review. The results are now being collected. These surveys have been carried out on plots laid out by the Chemistry Department as part of their work on forest nurseries.

The Decomposition of Chlorinated Aromatic Compounds by Soil Bacteria

The use of chlorinated aromatic compounds in soil makes it important to know the effect of micro-organisms on them and whether a population of organisms capable of attacking such a compound will be built up if it is added to the soil. Studies are being made with chloro- and bromo-naphthalene and with 2 : 4-dichlorophenoxyacetic acid and compounds related to it.

In the case of α-chloronaphthalene several soil bacteria have been found capable of attacking the compound, and the course of breakdown is being investigated. The organism that has been mainly studied produces a chloronaphthalene diol. N. Walker, in collaboration with G. H. Wiltshire of the Biochemistry Department, has produced evidence indicating that this diol is 8-chloro-1 : 2-dihydro-1 : 2-dihydroxynaphthalene. A later decomposition product appears to be 3-chlorosalicylic acid, but the intermediate breakdown products are not yet determined. The course of decomposition of α-bromonaphthalene seems to follow an analogous course through the diol to 3-bromosalicylic acid.

In the case of 2 : 4-dichlorophenoxyacetic acid, a strain of Flavobacterium has been isolated that will decompose this compound in pure culture, both in sterilized soil and in laboratory media, in which it can utilize it as the sole energy source. In soil, breakdown occurs only under aerobic conditions. Washed cells of the organism grown on a medium containing 2.4.D., will absorb oxygen in a Warburg vessel when supplied with this compound as substrate. There is no such oxygen uptake with 2 : 4-dichlorophenol as a substrate. In liquid media with 2.4.D., ionic chlorine is liberated. The Flavobacterium will also utilize parachlorophenoxyacetic acid, but will not utilize either orthochlorophenoxyacetic acid or 2-methyl-4-chlorophenoxyacetic acid. Attempts are being made by T. I. Steenson to isolate other organisms that can attack various chlorophenoxyacetic compounds. This work is in progress.

Nodule Bacteria and Leguminous Plants

(1) *The influence of hereditary factors in the clover plant on nodulation*

For some years past P. S. Nutman has conducted a series of genetical studies to determine the influence of hereditary factors in the clover plant on the time of appearance, number and effectiveness of nodules. He has continued the study of these factors, and is collating his results for publication. Hereditary factors influence the time at which nodules first appear, the number of nodules subsequently produced and the effectiveness of the nodules. For all these characters there are factors showing a complex heredity, that act independently of what bacterial strain is applied. In the case of nodule numbers and effectiveness there are also factors associated with simple recessive genes. One of these causes the production of numerous ineffective nodules with a normally effective bacterial strain. There is evidence of the existence of a second gene with similar effects. Both these genes show their influence with one particular bacterial strain only. A third gene has been tentatively identified that produces ineffective nodules which, however, are larger and less numerous. This appears not to be specific in its action with a particular strain of bacteria. Modifying factors also exist which can reverse the effect at least of the first gene, while the bacterial strain with which it shows its effect has given rise to mutants which restore the effective response. There is thus a very complex set of genetically controlled interactions which determine the number and effectiveness of nodules on the plant.

(2) *Nodule bacteria in the rhizosphere*

Miss Hilary Purchase continued her work on this subject, which, as previous reported, had shown that the population of nodule bacteria in the root surroundings of clover, even when it arose from a small inoculum, soon attained numbers far in excess of those required for maximum nodulation and independent of whether the plant was of a type that produced many or few nodules or was completely resistant to infection. The number of nodules produced must therefore be limited by some factor operating on the actual process of infection. Infection of the root is known to take place through the root hairs. In further work she has shown that, in

clover, the number of infected root hairs is related to the number of nodules finally formed, so that nodule numbers would seem to be determined by root-hair infection and not at some later stage of nodule development, as has been claimed in the case of lucerne.

While the growth of nodule bacteria when in pure culture in the root surroundings may not affect the number of nodules, competition between different strains outside the plant may well be of importance. In her rhizosphere studies Miss Purchase found that acute competition occurred between a strain and a mutant of that strain that was incapable of forming nodules, but that no such competition occurred between two strains of nodule bacteria, one from clover and one from lucerne. This finding has a bearing on the general problem of competition between micro-organisms, since it suggests that closely related strains may compete more acutely than those more distantly related. It also makes it unlikely that nodulation of a legume crop will be adversely affected by the previous growth of a different legume crop on the same land.

Nodule Bacteria in Acid Soil

Previous work has shown that clover nodule bacteria of an effective strain could produce completely ineffective forms when grown in sterilized soil. It has been found that soil type, and particularly its reaction, affects the production of such ineffective forms, which can sometimes be prevented by liming. A study is being made by Janina Kleczkowska of the survival and genetic stability of clover nodule bacteria in various soils and agar media at different pH values with and without calcium.

Bacteriophage attacking Nodule Bacteria (*Rhizobium*)

The influence of the enzymes Ribonuclease and Chymotrypsin on the interaction of *Bacteriophage* and *Rhizobium* has been made by Drs. Janina and A. Kleczkowski. The two enzymes behave differently, although both check phage multiplication, but neither affects the phage in the absence of bacteria. Ribonuclease interferes with the combination of phage with bacteria. Chymotrypsin does not affect this, but seems to act on the freshly formed phage–bacteria combination, making the phage inactive, but leaving the bacteria to multiply normally. The two enzymes differ also in the action of the bacteria without phage, ribonuclease seriously affects multiplication, whereas chymotrypsin has little effect on the bacteria.

BOTANY DEPARTMENT

D. J. Watson

Dr. Winifred Brenchley, who was head of the department from 1906 until she retired in 1948, died on 20th October, 1953. The department is proud of her achievements in many branches of agricultural botany, and especially of her pioneering work in the field of trace-element nutrition. All those who worked with her remember with gratitude the help that she gave with unfailing kindness and cheerfulness.

D. J. Watson was invited to give two lectures in a course on Photosynthesis organized jointly by the Netherlands Association for Agricultural Science, the Netherlands Institute of Agricultural Engineers and the Agricultural University of Wageningen, and held at Wageningen in September.

J. M. Thurston was asked to contribute a review of research on wild oats to the First National Weed Control Conference, at Margate in November.

Plant Nutrition

Dependence of manganese, molybdenum and vanadium toxicity on iron supply (K. Warington)

The toxicity of vanadium to flax, soybean and pea grown in solution culture has previously been found to depend on the concentration of iron on the solution (1952 Report, p. 65); it was more severe when the supply of iron was low, and could almost be eliminated if sufficient iron was given. Toxic effects of manganese and molybdenum have now been shown to depend similarly on iron supply (59).

Excess manganese (10 p.p.m.), molybdenum (40 p.p.m.) and vanadium (2·5 p.p.m.) all caused chlorosis of the shoot in soybean and flax, when the concentration of iron in the culture solution was low (1–5 p.p.m. Fe, according to the crop). Manganese excess had little effect on the root system, but molybdenum induced slight, and vanadium severe, root abnormalities. Raising the iron supply to 20 or 30 p.p.m. counteracted both the chlorosis and the root symptoms. Frequent small doses of iron proved less efficient in overcoming molybdenum or vanadium toxicity, but not manganese toxicity, than the same amount of iron given in larger quantities at longer intervals. When the concentration of Mn, Mo or V was low, iron had little effect on growth, but later experiments on flax and peas showed that iron given at the higher rates may itself be harmful.

Spectrographic analyses of soybean shoots (by H. H. le Riche, of the Soil Survey) showed that where increased iron supply had counteracted chlorosis caused by high Mn or V, the content of the toxic element per cent of dry matter was also reduced, but the content of Mo was not consistently changed by high iron supply. Root material is being analysed to find out whether the reduced content of Mn and V in the shoot resulted from decreased absorption or restricted translocation. The total iron content per cent of dry matter of the shoot was scarcely affected by variation in iron

supply, but it was greatly reduced by the high concentrations of Mn, Mo or V.

Nutrient uptake by excised roots (E. C. Humphries)

The rates of uptake of nitrogen, phosphorus and potassium from a nutrient solution by excised barley roots increase with increase in the reducing sugar content, but not with the sucrose content, of the roots (1952 Report, p. 66). Experiments have been made to find out whether glucose and fructose both influence nutrient uptake. Barley was germinated and grown in darkness for about nine days, supplied only with water. The low-sugar, low-salt roots so produced were cut off and placed in 0·01*M*-KCl solution to which 0·5 per cent glucose, fructose or sucrose had been added. The uptake of potassium in a 4-hour period, measured by the change in concentration of the solution, was then compared with the uptake from a solution without added sugar. Both glucose and fructose increased the rate of K uptake by about 15 per cent. The effect of sucrose was variable; the reason is not known and needs further investigation. Analyses of root samples, to measure the effect of the external sugar supply on the nature and amount of sugars present in the roots, are not yet complete.

Nutrient uptake from leaf sprays (G. N. Thorne and D. J. Watson)

Chemical analyses of material from sugar-beet plants, grown in soil in pots with factorial N, P and K fertilizer treatments, and sprayed daily with water or with solutions supplying N, P or K separately (1952 Report, p. 67) showed that uptakes of N, P and K from sprays were increased by N fertilizer, and unaffected by P fertilizer; K fertilizer reduced the uptake of K from spray. Increased nutrient uptake brought about by spraying was less effective in increasing dry matter yield than equivalent increase in nutrients brought about by fertilizer application, presumably because supply from the spray occurred later in the growth period than supply from fertilizers.

In this and earlier experiments the increased nutrient content of sprayed over unsprayed plants usually represented only about 50 per cent of the quantity of nutrients applied in the spray, as estimated from the difference between the volume of spray lost from the spray gun and the amount collected on blotting-paper placed round the plants during spraying. Analyses of the water used to wash the leaves before the plants were harvested showed the presence of only trivial amounts of P and K, and no N, so the incomplete recovery of nutrients from sprays cannot be attributed to nutrients accumulated on the outside of the leaves and washed off before harvest.

Another possible explanation of the apparent low recovery is that absorption of a nutrient by leaves from spray may reduce uptake of that nutrient by the roots, so that the difference in nutrient content between sprayed and unsprayed plants may not be a correct measure of uptake from the spray. This was tested by using isotopes to label nutrients supplied either to the roots or the leaves, so that amounts entering the plant by each route could be determined. Sugar-beet plants growing in soil were sprayed either with water or with ammonium nitrate solution labelled with ^{15}N, and

swedes growing in a ^{32}P-labelled nutrient solution were sprayed with water or normal sodium phosphate solution. In neither experiment was the nutrient uptake by the roots of the sprayed plants significantly less than that of controls sprayed with water, and, as before, only about half of the estimated nitrogen or phosphorus supply from the spray was recovered in the plants. It is still not possible to account for all the nutrients supplied in leaf sprays, and the fate of the fraction not recovered in the plant needs further investigation.

Further experiments were made on the effects of nutrient sprays on field crops (1952 Report, p. 67). As before, ammonium nitrate applied to winter wheat as a solution sprayed on the leaves during May and June produced about the same incease in grain yield as an equal quantity of ammonium nitrate applied to the soil at the same times, or as an equivalent top-dressing of "Nitro-Chalk" in April. The recovery of nitrogen in the crop was similar for all three methods of application. The effect of the spray treatment was no greater on plants that had previously received a spring top-dressing of nitrogen.

Earlier experiments had shown that the protein content of sugar-beet tops could be greatly increased by repeated spraying of the leaves with solutions of ammonium nitrate or urea in late September, without harmful effects on the yield of sugar, and spraying was more efficient than soil applications. As repeated spraying with a high volume of dilute spray would be impracticable on a commercial scale, an experiment was made to see whether similar results could be obtained from a single low-volume spraying with a nearly saturated urea solution. Two rates of spraying, supplying 32 and 64 lb. N in 12·5 and 25 gal. per acre respectively, were tested and compared with similar amounts of N given in four high-volume sprayings with a dilute solution. The concentrated spray caused some scorching of the leaves, especially at the higher rate of application, but increased the nitrogen content of all parts of the plant to about the same extent as the repeated spraying treatment did. Spraying at the higher rate increased the nitrogen content of the leaf lamina by 45 per cent, while equivalent applications of urea to the soil produced no detectable increase; the recovery of nitrogen from spray was much less than in previous experiments. The yield of sugar was slightly reduced by spraying, especially with concentrated solution at the higher rate.

The potash content of lucerne tops was increased by 24 per cent at the first cut and 35 per cent at the second cut by spraying with a solution of potassium sulphate, although the yield was unaffected (1952 Report, p. 68). The increases represent recoveries of 38 and 18 per cent of the potash applied. The increase in potash content produced by equivalent applications to the soil were only about one-third of those due to spraying.

Beneficial effects on plant growth from applications of phosphorus-containing insecticides, that could not be explained by control of insect damage, have been reported by several observers. It was suggested that these effects might be due to absorption through the leaves of the phosphorus contained in the spray, though the amounts of phosphorus involved seem to be far too small to be capable of producing measurable effects on growth. Brussels sprouts plants grown in pots, with or without phosphate added to

the soil, were sprayed six times with water, or with " Pestox III " or " Systox ", or with sodium phosphate solutions supplying the same amounts of phosphate as the insecticides. All the plants were kept free from insects by nicotine fumigation. None of the phosphorus-containing sprays had any detectable effect on the appearance, dry weight or phosphorus content of the plants, although large responses to the phosphate applied to the soil showed that the plants were very sensitive to change in phosphorus supply.

Weed Studies

Germination and dormancy of wild oats seeds (J. M. Thurston)

In the field experiment testing the effects of depth of sowing and varied cultivation treatments on wild oats seeds sown in October 1950 (1952 Report, p. 69) fewer seedlings of both *Avena fatua* and *A. ludoviciana* appeared in 1952–53 than in either of the two previous seasons. Less than 4 per cent of the seeds of *A. fatua* sown in 1950, and only 0·1–0·3 per cent of the seeds of *A. ludoviciana*, produced seedlings in 1952–53. Germination in both species appears already to be declining in the third year of the experiment, although so far less than 20 per cent of the seeds sown have produced seedlings that emerged above ground. Germination on plots ploughed in autumn or spring was similar to that on undisturbed plots, as in the previous year; frequent harrowing again slightly reduced the number of seedlings; deep-sown plots produced more seedlings than shallow-sown.

The wild oats infestation on the continuous spring-sown barley plots of Hoosfield consists of *A. fatua*, while that on the autumn-sown wheat plots of Broadbalk is nearly all *A. ludoviciana* with a few *A. fatua*. Since seeds of *A. ludoviciana* germinate mainly in autumn and winter, seedlings of this species are destroyed by cultivations for a spring-grown crop, and this presumably accounts for the absence of *A. ludoviciana* on Hoosfield. On the other hand, it is not obvious why *A. fatua*, which germinates in spring, should not become established in an autumn-sown crop. The rare occurrence of *A. fatua* in rye crops in Sweden has been attributed to the production by rye roots of a substance that inhibits germination of *A. fatua* seeds. A new field experiment was started on a heavily infested site in Hoosfield to test whether autumn or spring sowing is the main factor affecting the establishment of *A. fatua* in a cereal crop, or whether different cereals have specific effects. The germination and growth of *A. fatua* was compared on plots left fallow, or sown with wheat, rye or barley in autumn, or with barley in spring. In April the number of wild oats seedlings was inversely related to the weight of crop, the well-established autumn wheat and rye having least, autumn barley rather more and spring barley more still. All the cereal crops reduced the number of wild oats seedlings compared with fallow. This result indicates that the inhibitory effect of cereal crops depends on the size of the plants at the time when the wild oats are germinating, and does not suggest that rye or wheat have specific inhibitory effects. The crops were cut green, before the wild oats produced visible seeds, to avoid re-infestation. Just before cutting, the wild oats had fewer spikelets per plant and seeds per spikelet on the rye and wheat plots than on the barley

plots, and many fewer than on the fallow plots. Thus, autumn-sown cereals tend to reduce re-infestation with new seeds of *A. fatua* by reducing both the population of wild oats plants and their seed production.

In a pot culture experiment, plants of both wild oats species were grown outdoors or in a glasshouse, with and without shading, and with two rates of nitrogen application, to determine whether temperature, light intensity and nitrogen supply affect the onset of dormancy in the developing grain. Samples of ears were taken at intervals after emergence. Glasshouse conditions and shading both greatly increased the percentage of sterile spikelets. The percentage of viable seeds of both species, and of dormant seeds of *A. fatua*, increased more rapidly in the glasshouse than out-of-doors, but there was little dormancy in unripe seeds of *A. ludoviciana*. In another set of pots the effect of removal of whole panicles or parts of panicles on the growth, viability and dormancy of the remaining seeds was studied; this is relevant to attempts to control wild oats by cutting off the inflorescences above the cereal crop before the emergence of the cereal ears. The results of these experiments are not yet complete.

Physiological Studies on Virus Infection

Effect of a dark period on susceptibility of leaves to infection (E. C. Humphries, in collaboration with B. Kassanis, Plant Pathology Department)

The number of necrotic local lesions produced by tomato aucuba mosaic virus on tobacco leaves is increased if the plants are kept in darkness before inoculation, and the effect becomes progressively greater with lengthening of the dark period up to nine days. When plants are returned to daylight after a dark period before being inoculated, the number of lesions decreases as the length of the light period increases. The variation in lesion counts was shown to be closely correlated with changes in the nitrate content of the leaf lamina (1952 Report, p. 71); nitrate accumulates in leaves of darkened plants and decreases again when the plants are restored to daylight. Further experiments have consistently shown this correlation, but variation in lesion counts on similarly treated replicate leaves did not always reflect variation in nitrate content. Dry matter content decreases and the water content increases when tobacco plants are held in darkness, and these changes are both correlated with number of lesions. At present it seems possible that lesion count per unit area of leaf may be independently related to the nitrate, dry matter and water contents per unit leaf area, but this needs further investigation. Variation in nitrate content of the leaves induced by nitrogenous fertilizer had no effect on lesion numbers. Repeated spraying of the leaves with potassium nitrate solution before inoculation reduced the number of lesions, but this was presumably an effect of the salt outside the leaves, for addition of potassium nitrate to the inoculum also reduced the number of lesions.

Another way of increasing the susceptibility of tobacco plants to aucuba mosaic virus is to keep them at 37° C. in the light for one or two days; this treatment also has been shown to increase the nitrate content of the leaves.

Nitrate accumulates in discs of leaf lamina floated on water and held in darkness, and this suggests that the nitrate accumulated in leaves of darkened plants originates from proteolysis in the leaf, and is not transported from other parts of the plant.

Effect of infection with tobacco mosaic virus on the respiration of tobacco leaves (P. C. Owen)

Further work has been done to find out the conditions in which infection with tobacco mosaic virus affects rate of respiration of tobacco leaves (1952 Report, p. 72). In winter experiments, leaves rubbed with infected sap and immediately detached from the plant had a higher respiration rate in the first twenty hours after inoculation than comparable leaves rubbed with healthy sap, but no consistent increase by infection was found in summer. Experiments are in progress to find out whether this seasonal fluctuation can be related to variation in light intensity or day length.

Leaves taken from systemically infected plants three to four weeks after inoculation and showing mosaic symptoms usually had a lower respiration rate than comparable healthy leaves.

Effect of virus infection on transpiration (P. C. Owen)

Sugar-beet plants infected with beet yellows virus in the field appear to wilt less readily than healthy plants. The possibility that this might be due to a reduction by infection in the rates of transpiration was tested on plants grown in pots by measuring the rate of water loss from attached leaves to a stream of air drawn over them. The rate of transpiration per unit area was lower for leaves of infected plants that showed yellows symptoms than for comparable healthy leaves, but young infected leaves not yet showing symptoms had a slightly higher transpiration rate than healthy controls.

Systemic infection with tobacco mosaic virus caused a small increase in transpiration rate of attached tobacco leaves; infection with aucuba mosaic virus had a similar but larger effect.

Effect of infection with beet yellows virus on sugar beet (D. J. Watson and P. C. Owen)

Much time was spent on an attempt to measure the diurnal CO_2 exchange of whole sugar-beet plants grown in pots, with the object of determining the extent to which changes in the rates of photosynthesis and respiration are responsible for the reduction in net assimilation rate caused by infection (1952 Report, p. 73). No useful data were obtained, because the automatic gas-sampling unit previously used for respiration measurements with air-flow rates of about 200 ml./minute, was found to be unreliable for the high flow rates (3–4 litres/minute) necessary for the photosynthesis measurements. The unit has now been redesigned, and the investigation will be continued in 1954.

Growth Analysts

Dependence of net assimilation rate on leaf area index (D. J. Watson)

Previous work has shown that future improvements in crop yield are more likely to be effected through increase in leaf area per unit

area of land (leaf area index; LAI) than through improved photosynthetic efficiency as measured by net assimilation rate (NAR). As LAI increases, NAR must eventually begin to decrease through reduction in mean light intensity at the leaf surface caused by mutual shading of leaves, and possibly because of a fall in the atmospheric CO_2 concentration in the crop caused by crowding together photosynthesizing leaves. Such an interdependence of NAR and LAI presumably must set an upper limit to the rate of dry matter production per unit area of land, and hence to yield.

The effect of increasing LAI and NAR was measured in a field experiment on kale. Starting with a uniform population of closely spaced plants, LAI was varied by removing varying fractions of the plant population on different plots, and NAR was determined from the dry matter increments in a subsequent growth period. NAR was found to be independent of increase in LAI up to about 2·5, but decreased by about a quarter when LAI was increased from 2·5 to 4. This result shows that increase in leaf area per unit land area may lead to reduced photosynthetic efficiency of the leaves, even within the range of leaf area that can be achieved by present cultural methods, but the experiment needs to be repeated at different stages of growth and on other crops.

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

W. R. Smithies has been awarded a National Research Council of Canada Fellowship tenable for one year in the Department of Applied Biology of the National Research Council Laboratories, Ottawa. He left for Canada in August.

N. W. Pirie attended the 6th International Microbiological Congress in Rome and was a participant in the Symposium on "Interaction of Viruses and Cells" that was held in the Institute Superiore di Sanita at the same time.

D. Fairclough has joined the department to take charge of the work on large-scale preparation of leaf protein and on such other aspects of Biochemical Engineering as we are equipped to undertake.

The Oxidation of Indoleacetic and Indolepropionic Acid by Peroxidase Systems

(R. H. Kenten)

It is known that indoleacetic acid (IAA) is a principal native growth hormone of higher plants. A knowledge of the enzyme systems which control the proportions of IAA present in the plant is therefore important. Previous evidence suggested that manganese and peroxidase might be concerned in the oxidative inactivation of IAA, and in the hope that some evidence of the physiological role of manganese as well as the metabolism of IAA might be got, the oxidation of IAA and indolepropionic acid (IPA) by certain plant saps and other peroxidase systems has been studied.

The system in waxpod bean (*Phaseolus vulgaris*) root sap which catalyses the oxidation of IAA has been shown to consist of a thermolabile fraction and a thermostable fraction. The thermolabile fraction appears to be a peroxidase, and can be replaced by horseradish peroxidase. While both the thermolabile fraction and highly purified horseradish peroxidase preparations catalyse the oxidation of IAA by O_2, in the presence of the thermostable fraction the rate of oxidation is much faster. Evidence has been obtained which suggests that although the thermostable fraction contains several components, a large part of its activity is due to the presence of peroxidase substrates. Certain peroxidase substrates, e.g., monophenols, cause a large increase in the rate of oxidation of IAA by peroxidase, but if other peroxidase substrates, e.g., di- and trihydric phenols are also present in small amounts (10^{-5} or 10^{-4} M.) the oxidation is completely inhibited. The inhibition by these polyphenols can be reversed by the addition of an amount of H_2O_2 slightly greater than that required for the complete oxidation of the polyphenol by peroxidase. In this connection it is of interest that horseradish root sap, although rich in peroxidase, will not oxidase IAA unless it is first treated with a suitable amount of H_2O_2, suggesting the presence of inhibiting peroxidase substrates.

The mechanism of the oxidation is not clear, but at pH 6·5 or 7, which is around the optimum for catalase action, catalase inhibits strongly, suggesting that the reaction is accompanied by, and depends on, the formation of H_2O_2. The monophenols are active in catalytic amounts, and it seems likely from previous experience with such systems that they act via an oxidation–reduction cycle, being oxidized by peroxidase and reduced by IAA. Such a mechanism would account for the inhibiting effect of polyphenols, since these are more readily oxidized by peroxidase than monophenols, and would successfully compete for the H_2O_2 formed. It presupposes that polyphenols cannot act as oxidation–reduction carriers in the oxidation of IAA, but a similar situation is known with manganese oxidation by peroxidase and H_2O_2 where mono- but not polyphenols are active as carriers.

The oxidation of IPA differs from that of IAA in that it is not catalysed by peroxidase alone or by peroxidase plus monophenols. However, in the presence of small amounts of Mn^{2+} (10^{-5} M.) or the thermostable fraction of waxpod bean roots the oxidation of IPA by peroxidase proceeds readily. The oxidation of IAA by peroxidase is also stimulated by Mn^{2+} (10^{-5} M.) but the effect of Mn^{2+} is much less than that of the monophenols.

A Simple Method for the Preparation of Horseradish Peroxidase

(R. H. Kenten and P. J. G. Mann)

Of the two available methods for the preparation of highly purified horseradish peroxidase one requires the use of an electrophoresis apparatus, while the other involves many fractionation procedures. A simpler method has been devised which avoids the use of electrophoresis and considerably reduces the number of fractionation procedures. This method depends on the removal of much inactive material from the crude extract by precipitation with a mixture of chloroform and ethanol (Tsuchihashi's reagent). Following this treatment, highly purified peroxidase preparations have been obtained by fractional precipitations with ammonium sulphate and ethanol. The product is obtained as a stable dry preparation which can be crystallized from ammonium sulphate solution. The activity of the dry preparation varies from P.Z. 900 to 1,000. This compares with values of 930 to 1,220 given by other workers for " pure " horseradish peroxidase.

Plant Enzyme Reactions Leading to the Formation of Heterocyclic Compounds

(P. J. G. Mann and W. R. Smithies)

Work has been continued on plant amine oxidase and has mainly been concerned with a study of the formation of heterocyclic compounds resulting from oxidations catalysed by the enzyme. With aliphatic diamines of the αω series as substrates the enzyme-catalysed reaction has, in presence of catalase, generally been represented by the equation :

$$NH_2{\cdot}CH_2{\cdot}(CH_2)_n{\cdot}CH_2{\cdot}NH_2 + \tfrac{1}{2}O_2 \longrightarrow NH_2{\cdot}CH_2{\cdot}(CH_2)_n{\cdot}CHO + NH_3 \quad . \quad . \quad (1)$$

The reaction is an oxidative deamination, in which only one of the amino groups of the substrate is attacked, with the formation of an amine aldehyde. We have previously suggested that with 1 : 4-diaminobutane (putrescine) and 1 : 5-diaminopentane (cadaverine) as substrates the amine aldehydes formed undergo spontaneous cyclization to give unsaturated ring compounds by interaction between the aldehyde group and the residual amino group with elimination of water. This has now been established. By hydrogenation of the oxidation products using platinum black as catalyst, the corresponding saturated ring compounds, pyrrolidine and piperidine, have been formed and derivatives of these compounds isolated. If the product of the enzyme-catalysed oxidation of L-lysine undergoes similar ring closure L-pipecolinic acid should be formed on hydrogenation. Attempts to isolate this compound from the hydrogenated reaction mixtures have not yet been successful, though evidence of its presence has been obtained by paper chromatography.

With the αω series of diamines ring compound formation, as would be expected, depends on the length of the hydrocarbon chain. With 1 : 6-diaminohexane as substrate, evidence has been obtained of the formation of an unstable ring compound, while with 1 : 10-diaminodecane ring formation does not occur. The oxidation of the latter substrate takes place in two stages. With small amounts of enzyme it proceeds according to equation (1). With sufficiently large amounts of enzyme the O_2 uptake increases to 1 mol./mol. substrate with the formation of 2 mols. NH_3/mol. substrate. The results suggest that the amine aldehydes formed according to equation (1) are themselves substrates for plant amine oxidase but that when these compounds undergo spontaneous cyclization they are protected from further oxidation by the enzyme.

The possibility of ring compound formation following oxidation catalysed by plant amine oxidase is not confined to the oxidation products of the diamines and of L-lysine. We have previously shown that the oxidation of phenylalkylamine is catalysed by the enzyme and that with β-phenylethylamine as substrate phenylacetaldehyde is formed. It has now been found that the oxidation of *o*-amino-β-phenylethylamine catalysed by the enzyme leads to formation of indole. Presumably the product of the enzyme-catalysed reaction is *o*-amino-phenylacetaldehyde. It is known that *in vitro* this compound readily forms indole.

With suitable phenylalkylamines as substrates it should be possible to prepare quinoline, and possibly *iso*quinoline, ring compounds. This would complete the first part of the work, which aims at demonstrating that plant amine oxidase may be used as a tool in the synthesis of most of those ring compounds which form the framework of the plant alkaloids. The work should throw light on the synthesis mechanisms *in vivo* and may, in some cases, represent the actual mechanism. Thus it is now known that L-pipecolinic acid can be formed in the plant from L-lysine. The amine-oxidase-catalysed oxidation of L-lysine may well be the first stage of this reaction. If so, the plant should be able to reduce the unsaturated ring compounds formed from the amine aldehydes of equation (1). This is under investigation. By suitable oxidation of these unsaturated ring compounds pyrrole

and pyridine rings would be formed. We have already found that peroxidase catalyses the oxidation of these compounds, but the nature of the oxidation products has not yet been established.

Leaf Ribonuclease and Nucleoprotein

(M. Holden and N. W. Pirie)

Work has been continued on the purification and properties of leaf ribonuclease. All preparations of the nuclease which have been made so far also have phosphatase activity. Some of the properties of the phosphatase have been studied so that use can be made of differences in the two enzymes in finding a method of separating them. Ribonuclease and phosphatase are stable over the same pH range, and the nuclease is only slightly more stable to heat than the phosphastase. Precipitations with ammonium sulphate, ethanol, and acetone do not give a useful separation. The phosphatase is adsorbed from a dialysed solution on to calcium phosphate, but the nuclease is adsorbed to a much smaller extent. It is hoped to make use of this difference in making purer nuclease preparations. In the early stages of the purification of the nuclease, peroxidase is present. This enzyme can be removed by adding ribonucleic acid to a dialysed solution at pH 4; the nuclease and phosphatase are coprecipitated, leaving the peroxidase in solution.

Changes in nuclease and phosphatase levels during the early stages of development of pea seedlings have been followed. In ungerminated peas both enzymes are at a very low level, and there is a steep rise in the activity of both enzymes from the second to sixth day after germination. The activity per gram wet weight then remains constant until the tenth day, after which the nuclease falls slightly, though the phosphatase remains about the same. The total activity per plant continues to rise throughout the whole period of observation. At six days 70 per cent of the total phosphatase and nuclease activity is in the cotyledons, and at seventeen days about 30 per cent, whereas the activity in the shoot increases from 20 to 60 per cent of the total. The root has low activity of both enzymes, and contains only a small proportion of the total.

Various methods that have been used by other workers for measuring ribonuclease activity have been compared. The rate of enzyme action has frequently been measured by precipitation of unattacked ribonuclease acid (RNA). A number of precipitating agents have been used, ranging from acid alone (HCl, $HClO_4$, acetic acid) and acid + alcohol, to lanthanum and uranium salts. A reagent made up from uranyl nitrate in trichloracetic acid (TCA) has been widely used, and we have investigated in some detail the precipitation of RNA by it. The amount of P precipitated from a partly hydrolysed mixture, and therefore the apparent extent of hydrolysis, depends both on the concentration of the TCA used and on the concentration of RNA in the hydrolysate. There is less precipitation with more concentrated acid, and the lower the concentration of RNA, the greater is the apparent hydrolysis.

We are primarily interested in the kinetics of the action of leaf ribonuclease on leaf nucleoprotein and nucleic acid, but many experiments have been made with pancreatic enzyme on these two substrates and on yeast nucleic acid, and also with leaf enzyme

on yeast nucleic acid. This has led to a study of the components in commercial yeast nucleic acid, and some methods of getting uniform fractions from it have been developed. As a result, we now find that variations in the ionic environment affect the hydrolysis of some fractions from commercial yeast nucleic acid in substantially the same way as they affect that of nucleic acid made from the normal leaf or from tobacco mosaic virus. Other fractions more closely resemble leaf nucleoprotein. It is still not clear to what extent these differences are the consequence of the presence of varying amounts of enzyme inhibitors such as Fe, Cu and Ca. The point is of some importance, because they are able to act at physiological concentrations and so may play a part in the control of nucleoprotein metabolism, *in vivo*. We realize, however, that this whole investigation is taking us too far away from the original object of the research, and propose to finish it as soon as possible.

The Properties of Fractions from Virus Infected Leaves

(N. W. Pirie)

In recent years more widespread attention has been paid to the fact that virus infection leads to the formation of several anomalous proteins besides the one that is generally accepted as the virus. In particular, there are claims that tobacco leaves infected with tobacco mosaic virus contain a non-infective protein that is free from nucleic acid but still carries the serological activity characteristic of the virus. There is nothing intrinsically improbable in this claim, but we do not think that it has as yet been properly substantiated, and so have been re-investigating slowly sedimenting fractions similar to those that we made in 1944. No conclusion has yet been reached, but we are in the odd position that, although several other laboratories are now finding a large proportion of the anomalous protein in the slowly sedimenting fraction, we no longer find this. The cause of this change since 1944 is being actively looked for.

The factors affecting the loss of infectivity by tobacco necrosis virus have been discussed in recent Annual Reports. Our results are now relatively systematic, and during the past year none have contradicted the conclusion that virus preparations made by gentle methods may carry with them an enzyme system which, in the presence of a suitable substrate, robs the virus of its infectivity. We do not know what the substrate is normally, but it can be replaced by glucose and some other substances. Other explanations of the phenomena are, of course, possible; we hope soon to get evidence compatible with only one explanation. (In collaboration with F. C. Bawden.)

Metabolism of Tryptophan in Plants

(G. H. Wiltshire)

The reaction of tryptophan with hydrogen peroxide mentioned in the last report was further defined as a reaction of two molecules

of peroxide with one of tryptophan. The product was tentatively identified as 3-hydroxykynurenine. It has previously been suggested (Galston, A. V., *Plant Physiol.*, 24, 577, 1949) that tryptophan is converted in pea seedlings epicotyls to nicotinic acid through the intermediates kynurenine and 3-hydroxyanthranilic acid, and to indoleacetic acid. Neither kynurenine nor indoleacetic acid was detected in the products of tryptophan oxidation by the enzyme system studied here. The rate of production of hydroxykynurenine was faster, and the proportion of tryptophan converted to it greater than in the production of indoleacetic acid studied by Galston. Hydroxykynurenine was already known to be a product of tryptophan oxidation in rats and some insects, but had not been found in plants.

The Influence of Light on the Resistance of Leaves to Infection with Viruses

(G. H. Wiltshire)

Both the number of local lesions and the yield of some viruses are increased by shading or darkening the host plant before inoculation. Some changes produced by darkening in the nitrogenous constituents of bean and tobacco leaves were described by Humphries and Kassanis in the last report from the Botany Department.

The relative and absolute concentration of organic acids is also known to be altered by darkening, and experiments have been started to explore the relation between these changes and susceptibility. Ascorbic is one of these acids, and it is already known to inactivate viruses under some conditions and protect them from inactivation under others.

Leaves of French beans in normal greenhouse lighting in the spring contain about 0·6 m.equiv. ascorbic acid per 100 g. fresh weight. Young leaves contain more than old, and the content increases during the day and falls at night. The precise level depends also on the amount of sunlight received during the day or two before sampling. One-quarter of the acid is lost from plants shaded under muslin for two days, and one-half from plants in darkness. The loss from tobacco leaves similarly darkened is from 0·3 to 0·1 m.equiv. per 100 g. This loss occurs during a period of increasing susceptibility, but it continues until the concentration falls to zero, while susceptibility decreases if darkness is prolonged. When only one-half of a bean leaf is darkened, the ascorbic acid content of the darkened part falls by about one-tenth in two days and two-thirds in six days. At two days the darkened half produces three times as many lesions as the control half, while at six days both halves produce the same number.

Detached leaves standing in water in the dark lose ascorbic acid rather more slowly than the intact plant. The level can be restored to normal or even higher by standing the leaves in 0·005–0·05M-ascorbic acid solution, instead of water. Detached leaves become more easily infected if placed in the dark, just as does the intact plant. Leaves which had been darkened for two days, and in some of which the ascorbic acid level had been restored,

were inoculated with virus. Tobacco leaves containing 3·0 m.equiv. per 100 g. produced more lesions with aucuba mosaic virus than leaves containing 0·2 m.equiv. Bean leaves containing 1·2 m.equiv. produced as many lesions as those containing only 0·3 m.equiv. per 100 g.

The results show that the number of lesions produced on a leaf is not a direct function of the ascorbic acid concentration in that leaf. There is a coincidence of loss of ascorbic acid and increase of susceptibility when plants are darkened, but the loss at the time of greatest susceptibility is relatively small, and making up that loss does not confer resistance.

Technological Production of Leaf Protein

(D. Fairclough and N. W. Pirie)

Last year the Annual Report contained an article, "Large-scale production of Edible Protein from Fresh Leaves", which summarized work that has been done during the last thirteen years. It also suggested that the time was ripe to get the first part of this work to a definitive stage with machinery for the reliable production of protein in bulk for feeding trials. During the past year there have been no experimental advances, but a building for the work has been erected and machinery is being made and designed. Production should start in the spring of 1954.

The Properties of the Resistant Parts of Fungal Mycelium which would Accumulate in Soils

(M. V. Tracey)

An intensive investigation of conditions under which the "non-chitin glucosamine polymer", referred to in last year's report, can be brought into solution has been undertaken, together with an examination of methods by which it can be hydrolysed with minimal loss of the products of hydrolysis. The use of sodium chlorite solutions seems to be the most promising method of bringing the material into solution, but the method is not completely satisfactory. Phenol, monochloroacetic acid and alkaline solutions are not successful. Many enzyme solutions from a variety of sources have been shown to have no effect on the material. Hydrolysis with hydrochloric acid results in little decomposition of the glucosamine formed, but has the disadvantage that subsequent determination of volatile acids, such as acetic, is not possible. Sulphuric acid results in more extensive decomposition of glucosamine, but its use under defined conditions appears hopeful. The results of work done in previous years have been amplified, and a number of papers are being prepared for publication.

During the year under review the preparatory work for and initial editing of a new comprehensive text-book on plant analysis has been undertaken with Professor Dr. K. Paech of the Botanical Institute, Tübingen. It is hoped to publish it in four volumes during the course of 1954–55; each volume is expected to be of

about 600 pages. The contributors, who are drawn from seven countries, include the following members of this Station :

N. W. Pirie (and R. L. M. Synge) (Biochemistry Dept.)	General Methods of Separation (IIA) Proteins, Peptides, Amino Acids, and Amides (IXA)
M. J. R. Healy (Statistics Dept.)	Principles of Bioassays (IID)
R. H. Kenten (Biochemistry Dept.)	Gas Analysis in Plant Investigation (IIH)
E. C. Humphries (Botany Dept.)	Mineral Components and Ash Analysis (III)
M. V. Tracey (Biochemistry Dept.)	Chitin (IVH)
F. A. Skinner (Soil Microbiology)	Antibiotics (XII)

Most of the material submitted is now in the press, but it is expected that the final editing and preparation of indexes will be a commitment in the coming year.

PLANT PATHOLOGY DEPARTMENT

F. C. Bawden

We had hoped to have a full season's use of the new insectary and glasshouses, but building delays meant that we did not start to use them until October. These, with the extension to the potting sheds and a new animal house, are valuable additions to our facilities, but we cannot yet report on the ventilation and other features of the glasshouse. The Dunholme Field Station was also improved by installing central heating in the laboratories and building a small seedling house.

F. M. Roberts resigned in September to join the Colonial Agricultural Research Service, and is now studying the " unknown disease " of coconuts in Jamaica. T. W. Tinsley's period of secondment to the West African Cacao Research Institute was extended for a further tour of eighteen months.

F. C. Bawden attended the International Congress of Microbiology at Rome in September, and, as the guest of the organizing committee, took part in a symposium on the *Dynamics of Virus Infection*, held in October at the Ford Hospital in Detroit. R. Hull visited Holland and West Germany in September, to see large-scale experiments to test the value of insecticides in controlling beet yellows. He also attended the meeting of the International Institute of Sugar Beet Research at Bergen op Zoom in December; so, too, did J. W. Blencowe, who spent some time studying the serological techniques used by Dutch workers with plant viruses.

G. A. Salt was awarded the degree of Ph.D. of London University.

Viruses and Virus Diseases

Variations in infectivity of virus preparations

In previous reports we have commented on the variable infectivity of preparations of the Rothamsted tobacco necrosis virus (RTNV). Preparations made by sedimenting the virus from freshly extracted sap are, weight for weight, less infective than preparations made by centrifuging sap that has aged for a day or so at room temperature. This difference seemed to suggest that virus particles could acquire infectivity *in vitro*, but further work makes this idea less likely. It now seems probable that infective sap contains an enzyme that can destroy infectivity without destroying the physical integrity of the virus particles. The enzyme is unstable in sap and has little effect on the virus in sap, but it sediments with the virus when fresh sap is ultracentrifuged, and is stable and active in partially purified preparations of RTNV.

Workers in the U.S.A. have reported that sap from plants infected with tobacco mosaic virus (TMV) contains, in addition to specific nucleoproteins, proteins that have the serological characters of the virus but that contain no nucleic acid. As yet we have not identified any such particles, though we have several times sought

them. We have confirmed our earlier conclusions that sap contains specific particles of various sizes and that the small ones have little or no infectivity, but we are now finding that the ratio of small to large particles in fresh sap is much smaller than we recorded some years ago. (Bawden and Pirie.)

The rate of virus multiplication

As a preliminary to studying the factors that affect virus multiplication, detailed experiments have been made on the rate at which viruses multiply in inoculated leaves. Assays on extracts from leaves macerated at different times after inoculation show the same three phases with all viruses and hosts studied. First, there is a period during which infectivity decreases; this is followed by a period of rapid increase, which passes into a third, during which infectivity still increases, but at an increasingly slower rate. The shortest time after inoculation at which newly-formed virus was detected varied with different viruses and host plants. At 20–25° C., it was 10 hours for RTNV in French bean, 24 hours for RTNV in tobacco and 40 hours for TMV in tobacco and *N. glutinosa*. Experiments in which inoculated leaves were exposed to ultraviolet radiation, suggest that these times are probably at least twice the minimum required for new virus to be formed. As reported last year, irradiation appears to affect virus only when it is in the epidermal cells. Irradiation 6 hours after inoculation halves the number of infections produced by RTNV in French bean, and irradiation after 20 hours halves the number produced by RTNV and TMV in tobacco. These times are thought to indicate the time required for the inoculum to multiply in the epidermis cells and new virus to pass from there to deeper cells; this move seems to occur before free virus can be detected in leaf extracts. With RTNV in French bean, the times needed for successive ten-fold increases in infectivity of leaf extracts, starting 19 hours after inoculation, were 3, 7, 10 and 19 hours. During the first day after inoculation, virus multiplies predominantly in the epidermal cells, but after this most is produced in the chlorenchyma. (Harrison.)

Heat therapy

Last year we reported that growing plants at 36° could be used to establish virus-free progeny from parent plants systemically infected with tomato bushy stunt and a carnation virus. Many cuttings taken from side shoots or the main stem of plants kept continuously at 36° for ten or more days developed into healthy plants. The result has been confirmed and the work extended to other viruses, most of which seem to multiply poorly at 36° and many, including some with high thermal inactivation points, not enough to maintain themselves. Virus-free progeny were established from variegated *Abutilon*, and from plants infected with cucumber mosaic and tomato aspermy viruses. With the last two, striking cuttings was not always necessary, for many of the heated parent plants themselves were wholly freed from the infecting viruses and remained healthy when kept for months in ordinary glasshouse conditions. No healthy plants were established when cuttings were taken from treated plants infected with tobacco

mosaic, potato X or tomato spotted wilt viruses, though the virus content of plants kept for fourteen days at 36° was much less than that of comparable plants at 20°. (Kassanis.)

Electron microscopy

Electron microscopy has continued to be used in the routine examination of virus preparations, but most time has been occupied in improving techniques, particularly for preparing sections of leaf cells. When clear pictures of tobacco mosaic virus were obtained in sections from infected leaves, attempts were made to use electron microscopy to discover the sequence of events involved during infection. These failed, partly because sections contain only parts of a few cells and, in the early stage of infection, the virus occurs in detectable quantities in only a small proportion of the cells. Also, although with winter-grown plants fixation was good enough to identify virus particles in the cytoplasm, it was not good enough to do so in such structures as chloroplasts. With the harder cuticle of summer-grown plants, fixation was worse, and treatments were sought that might help the fixative to penetrate without damaging the cell contents. Of many treatments tried on intact pieces of leaf, the best was rinsing in 10 per cent " Teepol ", but still better results have been obtained recently by removing one epidermis before putting the leaf in fixative. This method has shown that the buffer containing the osmium tetroxide fixative affects fixation, and that the chloroplasts are better preserved if the leaves are left in fixative for 24 hours instead of for 2, as was the previous practice. The nuclei, however, are better preserved with the short exposure to the fixative. Dissolving the plastic embedding material is a slow process, and also seems to harm delicate structures in the cells; by cutting sections thin enough (0·05 μ or less), and modifying the microscope suitably, the plastic can be left in place without obscuring fine details.

The spray method devised by Backus and Williams for counting particles has been modified to produce small drops. An " Aerograph " spray gun makes a satisfactory substitute for their glass spray with concentric jets, which is difficult to make accurately. The drops from the gun are sorted and collected in a " Cascade Impactor ", instead of being allowed to sediment erratically on grids placed 30–40 cm. from the spray. By this method small drops (1–2 μ across) can be selected, and this allows examination at the high magnification needed to count the small particles in preparations of RTNV. Some of the larger particles in preparations of this virus seem to become flattened by surface tension when the droplets dry, and the method is now being adapted to combine the advantages of collecting drops by impaction with rapid freeze-drying. This technique also promises to be valuable for examining the structure of clay aggregates by electron microscopy. (Nixon and Fisher.)

Effects of ultra-violet radiation on proteins

To compare their behaviour with that of viruses, antibodies and chymotrypsin were irradiated with ultra-violet light. The inactivation of both follows the course of a first-order reaction.

The quantum yield for antibodies is about 10^{-3}, falling between the value for viruses and smaller proteins, further evidence that quantum yield and particle weight are inversely proportional. This fact suggests that the same amount of radiation energy must be adsorbed by each unit weight of a protein to inactivate specific biological activities. In some conditions irradiated antibody combines with other serum proteins to form complexes, which, although they still combine specifically with their antigens, behave differently from normal antibodies in precipitin tests. As with complexes formed when antisera are heated, the behaviour of the irradiated antisera depends on the character of the antigen. Unlike the plant viruses studied, but like a *Rhizobium* bacteriophage, chymotrypsin that is still active after exposure to ultra-violet is less stable than unexposed enzyme. When tobacco mosaic virus is exposed to much more radiation than is needed to destroy its infectivity, its resistance to denaturation by heat is decreased.

Ribonuclease and chymotrypsin, both of which inhibit infections by plant viruses, also inhibit infections of *Rhizobium* sp. by bacteriophages. The two enzymes seem to act in different ways. Chymotrypsin does not interfere with the combination between virus and bacterium, but interferes with some process that occurs immediately after they combine, whereas ribonuclease interferes both with the combination and also slows the growth of the bacteria. (Kleczkowski.)

Virus diseases of carnation

Most commercial stocks of common carnation varieties seem to be virus-infected, but the viruses concerned and their relative importance have been little studied. Infected carnations often show no clear leaf symptoms, but their infected state is usually shown by inoculating sap from them to sweet william (*Dianthus barbatus*) plants, which are hosts of all the carnation viruses and react to most by showing much clearer symptoms than do carnations. One virus, widely distributed in carnations, will infect tobacco and French bean, but these species rarely become infected when inoculated with sap from infected carnation or sweet william plants, because the sap contains substances that strongly inhibit infection of both tobacco and French bean.

Four distinct viruses have been isolated from commercial stocks of carnations. Two (including the one that infects tobacco and French bean and has previously been recorded in Holland) have spherical particles, a thermal inactivation point above 80°, are easily purified, and plants can be freed from them by exposure to 36° for fourteen days. No insect vector has been found for either. The other two viruses have elongated particles, a thermal inactivation point below 65°, and both are transmitted by *Myzus persicae*. Growing plants at 36° has not freed plants from either. The existence of one of these was recognized solely from serological tests and electron microscopy. It produces no external symptoms in either carnation or sweet william, but its transmission to and multiplication in them can be detected serologically or by examining sap in the electron microscope. Sugar beet has recently been found to be susceptible, and this plant is the only one yet discovered that shows symptoms of infection, the older leaves sometimes

becoming chlorotic. Whether this virus occurs in field crops of sugar beet is unknown. (Kassanis.)

Viruses of cruciferous crops

Studies on the transmission of cabbage black ringspot (CBRSV) and cauliflower mosaic (CLMV) viruses, by *Myzus persicae* and *Brevicoryne brassicae*, showed considerable differences between the behaviour of the two viruses and slight differences between the two aphids. Most infections with CBRSV and *M. persicae* were obtained when previously fasted aphids were fed for 2 minutes or less on infected plants, but the numbers of *B. brassicae* that transmitted increased with infection-feeding times up to 30 minutes, after which they decreased. With short infection-feeding times more *M. persicae* than *B. brassicae* transmitted, but with infection-feeding times of 1 hour or longer, equal numbers of both species transmitted. *B. brassicae* ceased to be infective within 2 hours of leaving infected plants, whereas *M. persicae* remained infective for 6 hours when fasted. More aphids of both species transmitted CLMV when given infection-feeding times of 1 hour or more, than when given infection-feeding times of 2 minutes. With the 2-minute infection feedings, the proportion that transmitted was increased if the aphids were previously fasted, but even so, it was less than with prolonged infection feedings. Experiments with leaves exposed to ultra-violet radiation suggests that CBRSV occurs in greater concentration in the epidermis than in other cells of infected leaves. The differences between the behaviour of the two viruses suggest that CLMV is more uniformly distributed through the various tissues of infected leaves. The differences between the behaviour of the two species of aphids in transmitting CBRSV can be partially explained by the asumption that fasting affects their feeding habits differently, and that *M. persicae* after fasting are more likely to imbibe sap from the epidermis. Fasting aphids can still infect healthy plants with CLMV as long as 6 hours after leaving an infected plant. *Myzus circumflexus* transmitted CBRSV from infected turnip to tobacco. (Watson and Hamlyn.)

Field experiments in conjunction with the National Agricultural Advisory Service were done in different parts of the country to see how the incidence of virus diseases was affected by surrounding cauliflower seed beds with narrow strips of barley, kale and broad beans. Aphids were so few in the spring that there was little spread of CLMV or CBRSV, but wherever the viruses occurred, their incidence was decreased by the barriers, particularly of barley. Seedlings surrounded by barriers grew better than unprotected ones, and up to 10 per cent more plantable ones were obtained.

Winged aphids produced on plants infected with CLMV were collected as they migrated, and were placed singly on turnip seedlings to see what proportion was infective. Of 191 tested, thirty-five infected the turnips.

A new form of sticky aphid trap was constructed to be used for a survey of virus diseases of cauliflower crops that the National Agricultural Advisory Service is making. The sticky surface is horizontal and placed level with the surface of the crop; comparisons with the old type of cylindrical trap suggest that it will

give a truer picture of aphids entering, leaving or moving within the crops, for the older type of cylindrical trap mainly caught windborne aphids.

Plots of various crops were again grown and regularly observed for their populations of *Myzus persicae* and other aphids. The results so far obtained, with all species recorded, agree with those reported by Kennedy with *Aphis fabae*, in showing that aphids preferentially infest tissues that are either rapidly growing or becoming senescent.

The multiplication of *M. persicae* on healthy and virus-infected cauliflower plants was compared by infesting caged plants and counting the aphids one month later. Although four times as many aphids were produced on the infected plants, the difference was barely significant, because the variations between individual plants were so large.

Turnip yellow mosaic virus was diagnosed in several kinds of cruciferous crops, and did much damage in Northumberland. Some of the isolates of this virus seem to differ from those previously described. (Broadbent and Heathcote.)

Potato virus diseases

As in previous years, the overhead irrigation of potato crops did not significantly affect the spread of potato viruses.

In a field experiment done in conjunction with the insecticides Department, Majestic potatoes were sprayed with five insecticides. Late in July, the unsprayed plots developed the largest population of *M. persicae* recorded at Rothamsted for many years, but none of the sprayed plots became infested. Effects on the spread of viruses will not be known until 1954. Excellent control of aphids was also obtained by spraying two commercial potato crops in Essex, the second year of a test to see whether insecticides will prolong the useful life of seed stocks there. When planted, the stocks were free from leaf roll and severe mosaic, but in the second year 1 per cent of the plants had leaf roll; 2 per cent in one crop, and 5 per cent in the other, had severe mosaic. These diseases occurred to the same extent whether the plots were sprayed or not in 1952. As expected, the insecticides did not prevent viruses from being introduced into healthy crops, and it will not be known until next year whether they affect the spread from infected plants within the crop. Further information on this series of experiments on virus control is given in the report of the Insecticides Department. (Broadbent.)

Sugar beet virus diseases

Experiments were started to devise methods for assessing the relative susceptibility of sugar-beet varieties to yellows. Twenty varieties supplied by the Plant Breeding Institute, Cambridge, were tested by colonizing thirty seedlings, ten each being colonized with one, five and ten aphids. The properties of the plants that developed symptoms was taken as an index of susceptibility, and the severity of symptoms was also recorded to give some measure of tolerance. Varieties from *Beta maritima* showed less severe symptoms than *Beta vulgaris*, but both types were equally susceptible to infection.

Serological tests showed that *B. vulgaris* plants also contained more virus, and *B. maritima* plants with more severe symptoms contained more virus than those with mild symptoms. Plants with slight symptoms in the glasshouses often became severely chlorotic when grown in the open, whereas seedlings that had shown severe symptoms sometimes recovered when grown in the open, the appearance of recovery being helped by the death of the yellow leaves. (Watson.)

Experiments at Dunholme comparing the reaction to yellows of inbred lines of sugar beet also sometimes gave different results when comparisons were made between seedlings in glasshouse or plants in the field. Line M9, for example, reacted severely in the glasshouse, but in the field was greener and less stunted than N4, which in the seedling stage under glass showed only very faint symptoms. Reductions in yield of sugar from infection reflected the severity of symptoms shown in the field. Thirty-seven inbred American lines of beet were all found to be susceptible. A comparable range of reaction to infection was noted as in our inbred lines. Whereas seedlings of some lines showed etching of the veins rapidly and soon became necrotic and stunted, seedlings of other lines took much longer to show symptoms, which then were also usually milder, some giving only restricted yellow blotches on a few leaves. (Hull.)

The study of viruses isolated from beet showing symptoms of different type and severity suggests that there may be more than one cause for the disease normally called " yellows " in field crops. Many isolates have been found that cause yellowing but no etch or other necrotic lesions, and sap from plants infected with these has consistently failed to react with antisera prepared against isolates that cause necrosis. Similarly, when sap from diseased plants has been examined with the electron microscope, filamentous particles have been found only when the plants showed necrotic symptoms and when their sap precipitated strongly with antiserum. Plants showing yellowing only developed veinal necrosis as rapidly as previously healthy plants when they were infected with virus from plants with necrosis. Plants so infected were more chlorotic and stunted than were plants infected with either isolate alone. Whether the isolates that cause these different effects are distinct viruses or related strains remains to be established; those causing necrosis occur together in the same crops and often in the same plants as those that do not. All seem to be transmitted similarly by aphids. (Hull and Blencowe.)

The series of field experiments on the effects of date of sowing and time of singling sugar beet was finished. Again only a small percentage of the plants contracted yellows, and they not until after the latest singling. In nine experiments done at Rothamsted, Dunholme and the Norfolk Agricultural Station, Sprowston, between 1950 and 1953, only once has the time of singling greatly influenced the incidence of yellows. On that occasion there was an unusually early migration of aphids, and a much smaller proportion of the plants became infected on the plots which had not been singled. The incidence of yellows has usually been affected by date of sowing. In years when aphids arrived early, plots sown in March had more plants infected than did plots sown in May. More usually, however, the aphids arrived in late June or July, and then the late-sown beet had more infected plants than the early-sown.

The May-sown beet also had larger populations of apterous aphids, especially *Aphis fabae.*

Late singling decreased plant populations and yields unless "rubbed" or "de-corticated" seed was used. Sowing seed in March usually gave the biggest yields, except when weather caused much "bolting". (Blencowe.)

Samples from all beds of sugar-beet stecklings sown in the United Kingdom were planted at Dunholme. Those used for planting commercial seed crops in June averaged 2·6 per cent plants with yellows. Steckling beds in the north of England had exceptionally heavy aphid infestations, and they had a mean of 4·1 per cent infected plants, compared with 1·9 per cent for beds in the Eastern Counties sprayed with insecticide and 1·3 per cent for beds grown there under a cover crop and sprayed. Seven beds were rejected because they had more than 1 per cent infected plants in the autumn. Samples from six of these beds gave from 6 to 63 per cent infected plants. Nine beds passed for planting gave 5–10 per cent infected seeders, three 10–15 per cent and two gave 22 per cent. Most of these were from beds in the north.

In the autumn of 1953, fifty-one out of eighty-six steckling beds showed less than 1 per cent of plants with yellows. Ten beds contained more than 10 per cent infected plants. The mean percentage in sixty beds which will probably be used for 1954 seed crops is 0·61 per cent compared with 0·22 per cent in 1952, 0·09 per cent in 1951 and 0·21 per cent in 1950. Beds in the isolation areas were generally satisfactory, twenty-one showing less than 1 per cent yellows, six between 1·8 and 2 per cent, and one bed in the Tweed Valley 5 per cent. The worst were in the Eastern Counties, where spraying did not adequately prevent infection. Of forty-nine beds sprayed, only eighteen had less than 1 per cent infected plants, sixteen had between 1 and 5 per cent and fifteen had over 5 per cent. In Bedfordshire sprayed beds were better, and beds sown under cover crops, and sprayed after the cover crop was cut, have very few infected plants. (Hull and Osborne.)

As soon as stecklings emerged at Dunholme this year, they were colonized by many alate *Myzus persicae,* and none of seven systemic insecticides used prevented yellows from developing. Early spraying probably gives poor results because little insecticide is absorbed by small seedlings, and extra seedlings emerge after the spraying. Soaking the seed in systemic insecticides before planting, or watering them on to the soil when the seedlings were beginning to emerge, prevented the seedlings from becoming colonized by aphids, but it also decreased the stand of seedlings.

Experiments to test the effect of spraying root crops with systemic insecticides on the incidence of yellows were continued. They showed that the effect of two sprayings varies greatly from year to year and from crop to crop, depending on the nature of the particular outbreak. When only a few plants are infected by aphids that bring virus into the crop, and most of the yellows results from secondary spread within the crop, then insecticides greatly decrease the incidence. In these conditions, however, the losses in yield from yellows are small, and although spraying may decrease incidence by factors of from 2 to 5, the treatment is unlikely to be an economic proposition. When infection occurs early and

many plants in a crop are infected by incoming aphids, then all the plants on sprayed and unsprayed plots may become infected. In these conditions, spraying simply delays, by two to three weeks, the time when the crop becomes 100 per cent infected. However, as yield of sugar is greatly decreased by infections early in the life of plants, this delay in time of infection may be useful, and these are probably the conditions in which spraying gives the greatest return, despite its apparent lack of effect. (Gates.)

Systemic insecticides were sprayed on fodder-beet crops a few days before lifting to see whether they would kill aphids and so prevent them from infesting clamps. A field crop of fodder beet, variety Hunsballe X, was sprayed with 0·2 per cent parathion at the rate of 100 gal. per acre, on 11th November 1952, and lifted and clamped three days later, before the plants could become reinfested with winged aphids. In the following April no aphids, or any other arthropods common in clamps, such as spiders, gnats, and flies, were found in the clamp of sprayed fodder beet, whereas a control clamp of unsprayed beet was infested with aphids (*Myzus persicae* Sulz) and other insects. "Systox," parathion and "Pestox 14" were tested to find the concentration needed when spraying fodder beet in October to kill all aphids that feed on cut leaves. All three need to be applied at three times the concentrations normally used on sugar beet in the summer.

In addition to using insecticides to prevent aphids from being introduced into clamps, maleic hydrazide, a growth-regulating substance, was tested for its ability to check sprouting of stored roots, with the idea that this might decrease infestations. Mangolds were sprayed with 0·25 per cent maleic hydrazide in the field on 15th October 1952 and were clamped in the usual way, with unsprayed mangolds acting as a control. In the following April the sprouts on the sprayed plants were only half as big as those on the controls. In another experiment Klein E sugar beet was sprayed with 1 per cent maleic hydrazide on 5th November 1952, harvested on 21st November and stored in damp sand in a cellar. Sprayed and unsprayed plants both started to sprout immediately, but by February differences were apparent, for the sprouts on the sprayed plants were then 2 inches long, whereas those on the unsprayed were 4 inches. In July 1953, when the control shoots were 18 inches long, the sprouts of the sprayed plants were only 4 inches. (Cornford.)

Of various weeds tested, three were found susceptible to sugar-beet yellows. The leaves of infected *Senecio vulgaris* became yellow, thick and brittle. Passage through this host did not affect the type of symptoms produced in sugar beet by mild and virulent isolates. In one test with *Capsella bursa-pastoris*, infected plants were stunted, but in another they were indistinguishable from uninfected plants. Even when a virulent isolate was used, the virus recovered caused only mild symptoms in beet. *Stellaria media* showed no symptoms when infected, but sap from infected plants reacted strongly with virus antiserum. Isolates virulent to beet were recovered apparently unchanged by passage through this host. (Hull.)

Mycology

Spore dispersal

The wind tunnel was moved to a specially designed wooden building, so that outdoor air can be used and plants kept alive in the tunnel for several days at a time. Using a modified version of the Hirst spore trap designed to put in the wind tunnel, the production of spores by plants kept under known wind conditions was studied and compared with the results obtained by trapping in the open.

Tests so far have been done mainly with wheat and barley plants, heavily infected with powdery mildew (*Erysiphe graminis*). At a constant wind speed of 2 m.p.h. spores were liberated with the same diurnal periodicity as found by Hirst when using the suction trap in the open. Spore liberation therefore appears to be independent of wind speed. Keeping the plants in constant light, or in constant darkness, for periods up to 72 hours did not change the diurnal periodicity, which is evidently not determined by light or darkness. Other variables, such as temperature and humidity, have yet to be examined. Potato shoots severely affected with potato blight did not produce spores in the wind tunnel, presumably because the relative humidity was too low. A small tunnel through which conditioned air can be passed, is being made to study the liberation of *Phytophthora infestans* spores. (Gregory; Hirst; Last; Stedman.)

The deposition of air-borne spores on plates charged to 4,000 volts (positive or negative in respect to earth) has been studied using electronic equipment designed and made by H. L. Nixon and H. L. Fisher. When *Lycopodium* spores are blown from a glass tube some are apparently negatively charged, but more appear to be charged positively, and others carry no charge. Vertical metal plates charged to 4,000 volts, arranged either parallel to or at right angles to the wind direction, catch up to ten times as many spores as they do when earthed. (Gregory and Stedman.)

Casella Ltd. are marketing a commercial model of the Hirst automatic spore trap, and this was calibrated against the "Cascade" Impactor, using both large (*Lycopodium*) and small Mushroom spores. (Hirst and Stedman.)

A portable hand-operated volumetric spore trap was designed for use where there is no power supply and the Hirst automatic trap cannot be worked. The apparatus was tested under a variety of conditions to find its advantages and limitations. It is particularly valuable for making many measurements of the spore content at short time intervals, and for studying how spore concentration varies at different distances from their place of liberation. (Gregory.)

The automatic spore trap was used to study the dispersal of ascospores and conidia of the apple scab fungus (*Venturia inaequalis*), the spore concentration in wheat stubble infected with *Ophiobolus graminis* and *Cercosporella herpotrichoides*, and in commercial mushroom-growing houses. (Gregory and Hirst.)

Potato blight

In the hope of improving disease forecasting, the correlation between weather and infections by *Phytophthora infestans* was again

studied in four parts of the United Kingdom, where the weather was recorded, both in screens 4 feet above the ground and in potato crops. At Rothamsted conditions affecting the liberation of spores, and the conditions that allow them to infect, were further studied by measuring the concentration of *P. infestans* spores in the air and finding when potted potato plants, which were placed in the potato field each day, became infected. The progress of the disease on individual shoots was recorded to study in what way modifying the ecoclimate, by irrigation at different times of the day, or by preventing the deposition of dew, affected spread. Although the treatments were not started until blight had already occurred, increasing water increased infection in both foliage and tubers.

A continuously recording dew-balance was made that measures the amount of water deposited on a potato shoot and the length of time for which water deposits persist. This should allow the importance of water films in affecting potato blight to be tested adequately.

Potato blight in 1953 was recorded at Rothamsted on 23rd July, the earliest outbreak since records were first taken in 1940. The disease spread moderately fast until September, when dry weather stopped it. Experiments in which Majestic potato crops had two well-timed copper sprays and the haulm was killed with sulphuric acid, showed that these measures increased yield of tubers by only $\frac{1}{2}$ ton per acre. A tractor sprayer with an eight-row boom passing through the crop three times reduced yield by about 7 cwt. per acre. Less than 1 per cent of tubers from sprayed or unsprayed plots had blight. During the dry weather in September, the weight of tubers decreased by about 1 ton per acre when the haulm died. Loss of water to the dying haulm or to the soil may be the cause, but unfortunately dry weight was not estimated. The decrease occurred earlier on unsprayed than on sprayed plots; had the experiment been harvested when only the haulm of the unsprayed plots was dead, spraying would have seemed to have increased yield by about 2 tons per acre.

Powdery mildew of cereals

Studies on the effect of nitrogenous fertilizers (N) on the incidence of mildew (*Erysiphe graminis*) on winter wheat grown in pots were finished. Applying N to plants of different ages affected the incidence differently. When applied before the flag leaf had emerged, the infection-index (number of pustules per 100 sq. cm. of leaf blade) increased to a maximum and then declined. Applied after the flag leaf had emerged, the infection-index increased steadily without reaching a peak, and the increased susceptibility was not associated with an increased relative leaf growth rate as when N was applied earlier. Plants given N in either April or May had at least three times as many pustules as those given N in January. The time when N was applied did not affect the date when perithecia appeared. After adding N to nitrogen-deficient plants, the mature leaves, which had previously resisted mildew, became susceptible.

A series of field experiments was started to test the effect of date of sowing on the incidence of mildew. Barley was sown on four dates from 28th February to 22nd April 1953. Pustules were

first observed in mid-May. Subsequently the number of pustules per unit area increased rapidly, and the plants sown on 22nd April (fourth sowing date) were the most susceptible.

The spore content of the air within and above two mildewed cereal crops, (*a*) barley on the Garden Plots and (*b*) wheat on Broadbalk, was measured in June and July. Most spores occurred at the base of the crops, the concentration decreased rapidly near the top of the crop, and was always greater within the crop than in the air above.

The two most numerous types of spore are (*a*) *Cladosporium* and *Erysiphe* on dry days and (*b*) *Sporobolomyces* and *Tilletiopsis* on wet days. In Broadbalk wheat the concentration of spores varied greatly in different plots. *Erysiphe* conidia occurred at 10,000 per cubic metre of air on dry and wet days in the heavily fertilized Plot 8, but hardly occurred in Plot 3, which receives no manure. On wet days only, both *Sporobolomyces* and *Tilletiopsis* spores occurred at 200,000 per cubic metre of air at 10 cm. from the ground in Plot 8, whereas *Sporobolomyces* occurred in Plot 3 at only 22,000 and *Tilletiopsis* at 40 spores per cubic metre of air.

Isolation of *Sporobolomyces* sp. from leaves of field crops gave results comparable with those from spore trapping. Many more colonies were obtained on agar plates from leaves taken low in a crop than from higher leaves, and leaves from Plot 8 on Broadbalk gave many more than leaves from Plot 3. (Last.)

Cereal foot and root rots

Land which was infested by weeds and on which wheat was severely infected by eyespot (*Cercosporella herpotrichoides*) and take-all (*Ophiobolus graminis*) in 1949, was used to test the relative cleaning action of three years under different crops. Plots in which wheat (Squareheads Master) grown in 1953 was the first, second, third, and fifth consecutive crop of winter wheat or barley, gave respectively mean yields of 37, 28, 19 and 15½ cwt. per acre; these included 11, 20, 32 and 32 per cent tail corn; 16, 47, 82 and 63 per cent of the straws had eyespot and 0·3, 24, 34 and 45 per cent had take-all at harvest. Effects on weeds were equally spectacular; about 1,775 heads of wild oats occurred in 10 sq. yd. in the plot with the fifth consecutive wheat crop, whereas only two occurred in 10 sq. yd. in plots that had not carried cereals during the previous three years. Full records exist from this and another experiment to show how various rotations affected the incidence of fungus diseases (eyespot, take-all, sharp eyespot *Corticium* (*Rhizoctonia*) *solani*, brown footrot, *Fusarium* sp.), and insect pests (wheat bulb fly, Hessian fly and stem sawfly), the density of the crop, the prevalence of weeds, lodging and yields of grain and straw. (Glynne, Salt and Slope.)

A field experiment testing the effects of seed rate, rate and time of applying nitrogen, and spraying with sulphuric acid on two varieties of wheat was continued for a second year. The crop was the fourth wheat crop in five years and, in addition to eyespot, it developed take-all and became weedy; consequently yields were lower than before. Decreasing the seed rate from 3 to 1½ bushels per acre decreased take-all and increased yield by 3–5 cwt. per acre. Sulphate of ammonia applied at 0, 2 and 4 cwt. per acre

increased the area of Squareheads Master lodged from 22 to 51 and 58 per cent respectively, decreased take-all and increased yield from 14 to 18 and 19 cwt. per acre. The variety Cappelle did not lodge; the fertilizer decreased take-all and increased yield from 18 to 22 and 24 cwt. per acre. The lower seed rate and a heavy dose of nitrogen combined to increase yield of Squareheads Master from 12 to 22 cwt. per acre, and of Cappelle from 14 to 25 cwt. per acre.

Four years' work testing the effects of applying nitrogen at different dates to wheat have again shown that tillering is important in determining the incidence of eyespot. In pots, nitrogen given between October and April increased tillering early enough to delay infection of the straws, and so decreased the severity of lesions at harvest; when given in May tillering was too late to prevent the principal straws becoming severely infected, although young tillers escaped infection. In the field the effect of nitrogen in delaying infection of the straws was counteracted by its effect in increasing the luxuriance of the crop, which favoured the spread of the fungus. Nitrogen applied in October produced more tillers and fewer severe lesions at harvest than applications in March, April or May, which produced more luxuriant crops. (Salt.)

Annual surveys show that eyespot is the most important of the foot and root rotting diseases on the four- and six-course rotation experiments at Rothamsted. In the four-course experiment an average of 45 per cent straws were infected at harvest in the sixteen years 1938–53, the incidence varying from 3 to 86 per cent in different years; an average of 29 per cent straws were infected in the same period in the six-course experiment ranging from 2 to 80 per cent in different years. Sharp eyespot occurred in most years, brown footrot and take-all occasionally, but none seems important.

Six wheat varieties grown in pots differed in their reaction to eyespot. Of two high-yielding varieties, Cappelle yielded as much grain when infected by eyespot as did the four lower-yielding varieties when uninfected. Each variety suffered most loss when sown thickly and inadequately fertilized with nitrogen. No relation was found between tillering capacity and loss from eyespot. (Glynne.)

Clubroot of crucifers

Last year we reported the existence of races of *Plasmodiophora brassicae*. This has been confirmed, and an isolate from Norway was found to resemble isolates from Agdell field. The variety of swede called Wilhelmsburger, bred for resistance to clubroot in Denmark, is very susceptible to the Norwegian isolate.

The life cycle of the organism was studied by infecting plants grown in water cultures. A wide range of stages, from root-hair infections to mature galls, was obtained for histological examination.

Experiments on spore germination were made easier by making them in phosphate buffer instead of a full nutrient solution. Omitting nitrates has greatly reduced bacterial contamination and made it possible to lengthen the experimental period up to sixteen days. Variations in the germination of different spore suspensions experienced in previous years can partly be explained by the fact

that germination depends greatly on the age of the parent gall. Spores from old galls germinate more readily than those from young galls, possibly only because they are mature. Storing spore suspensions at 4–5° C. seems not to affect germination. Almost all stages of germinating spores have been seen, contrary to reports by other workers, flagella were seen only on zoospores which were almost completely liberated. (Macfarlane.)

Sugar-beet diseases

Diseases of seedlings caused by *Phoma betae* carried in the seed and by soil fungi were this year greatly decreased by Phygon dust (1 per cent); by soaking for 20 minutes in ethyl mercury phosphate solution (40 p.p.m. active material); and by Dow 9B dust (0·5 per cent). Phemox was less effective than the standard dressing, Agrosan. Dressing with a fungicide is most effective when the crop is sown early and the soil is cold, conditions in which many seedlings rot before they come above ground. (Gates.)

The introduction of mechanical harvesters for beet increases damage to roots and necessitates longer periods of storage. Work has therefore been started to find the extent of losses and their causes. Roots harvested from two fields differed little in sugar loss after storing until February in a cellar. Undertopped roots lost more sugar than overtopped ones. When sampled early in January roots stored fresh lost the same amount as dried roots, but by February the dried roots had rotted more. Bruising also increased loss and rotting. The mean loss of sugar was 7 per cent by early January and 10 per cent by early February. *Botrytis cinerea*, the main cause of rots, affected more roots from one field than from the other, was more severe on the dried roots, and on roots bruised to simulate the damage caused by mechanical harvesters, than on those harvested normally.

When beets were cut lengthwise and the freshly cut surfaces covered with *Botrytis* spores, the tissue under the crown to a depth of about ½ inch resisted infection. When this tissue was removed, as is done in " topping " the beet, the exposed surface was invaded when exposed to a concentrated suspension of *Botrytis* spores, but not when exposed to a dilute one. If the cut surface was exposed to the air for about a week, the surface cells became suberized and resisted attack. A wet cut surface also became a barrier to *Botrytis* germ tubes after only two days. (Hull and Cornford.)

NEMATOLOGY DEPARTMENT

B. G. Peters

T. Goodey died suddenly from a heart attack on the 7th July, a few weeks before his projected visit to Australia to advise the government there on nematological research and training. He was the most distinguished nematologist this country has ever had, and his death has been a great blow, not only professionally to nematology and to this department, but also personally to all members of the staff and to his many friends elsewhere. At the time of his death he was engaged in a study of species of *Anguina* from grasses and in preparing (with J. B. Goodey) a new edition of his text-book *Plant Parasitic Nematodes*.

B. G. Peters spent the three months April to June at the Connecticut Agricultural Experiment Station, New Haven, to advise them on nematological problems. He is most grateful to all the staff there with whom he came into contact for their extreme kindness. During this time he was generously given opportunities of visiting Cornell, Beltsville, and the two golden nematode laboratories on Long Island. In July he visited nematological laboratories at Ottawa, Salt Lake City, Berkeley, Modesto, Riverside and Seal Beach.

In July M. T. Franklin paid short visits to Wageningen and Lyngby, on her way to attend the 14th International Congress of Zoology at Copenhagen. Mr. N. Hague (Imperial College, London) and Mr. T. Mabbott (Department of Agriculture for Scotland) spent two weeks in the department acquiring experimental techniques.

Material and Methods

The department continues to receive much eelworm material for identification, most of this work being done by M. T. Franklin and J. B. Goodey. Populations of various species of *Meloidogyne* are building up well in the heated glasshouse beds, this material being used for morphological studies and for comparison with unidentified material sent in. (M. T. Franklin.)

The standard hatching test, for estimating the population of living larvae of *Heterodera rostochiensis*, involves soaking cysts in potato root diffusate for several weeks and counting the larvae which hatch from their egg-shells and emerge from the cysts. Great variability in the numbers of eggs within a cyst entails very high replication (several hundreds) in the cysts used. A new technique is under test wherein eggs are first removed from cysts and then treated with enzymes before being exposed to root diffusate; the object is to attain equal precision with the expenditure of fewer cysts and a much shorter time. (D. W. Fenwick.)

Two other techniques, developed elsewhere, are being tested. An established alternative to hatching *Heterodera* larvae was to grow indicator plants in infested soil, stain the root systems and count larvae within the roots; it now seems that this can be greatly improved by cutting up the roots in a homogenizer. Both hatching and the growing of indicators have been necessitated by the virtual

impossibility of deciding visually when a given larva, coiled up within its egg-shell, was living or dead. In the past much time has been wasted in seeking *intra vitam* stains which would differentiate these. It now seems likely that the fluorescence colours of larvae stained with acridine orange and examined by ultra-violet light will reliably distinguish living (green) from dead (red) larvae, at least under certain conditions. These two techniques have applications outside the *Heterodera* field. (C. C. Doncaster.)

Pre-soaking cysts in weak solutions of several ionizing and non-ionizing detergents, in order to facilitate the subsequent rapid diffusion of root-diffusate, has not proved satisfactory. (B. G. Peters.)

Host–Parasite Relationships

Under this general heading are grouped studies on life-histories, resistance and pathogenicity.

Life-histories

The life history of *Heterodera cruciferae* has been investigated by growing cabbage seedlings in heavily infested soil for two days, transplanting to clean sand and using nutrient solutions, and removing two to four plants daily for fixing and staining, over a period of five weeks. In this way all stages up to mature adults have been produced, each stage dated to within two days. (C. C. Doncaster.)

By sowing barley in November (1952) in soil infested with *Heterodera major*, and staining roots at intervals, it has been shown that there is a considerable invasion of roots during the winter months, whether the pots of barley were grown in a glasshouse or plunged outside. There had been doubts whether winter invasion by this species occurred. (A. R. Forster.)

The host ranges of several species of *Meloiodogyne* are being investigated. (M. T. Franklin.)

Resistance

Stringent pot tests and three field trials of several oat varieties for resistance to *Ditylenchus dipsaci*, in conjunction with the National Institute of Agricultural Botany, have shown that most varieties are susceptible. Of spring oats only Milford (S.225) is resistant; two or three winter varieties show promise, and work on these is continuing. In co-operation with the N.A.A.S., one field trial of the lucerne race of *D. dipsaci* has shown two lucerne varieties to be susceptible, and two others, along with most other legumes, to be resistant. A second field trial involving the carrot race of *D. dipsaci* is under observation. (J. B. Goodey.)

Not since 1935 has any extensive survey been made of the varietal susceptibility of potatoes to *D. destructor*. This year twenty-four commercial varieties have been tested both in pots (at up to 200,000 eelworms per pot) and in a randomized plot experiment in the Fens. No variety showed any resistance. The mushroom race of this species seems, in this country, to be almost entirely confined to mushrooms. Experiments on the biology of this race are in progress. (J. B. Goodey.)

Heterodera rostochiensis in potatoes may yet be controlled by

breeding into commercial varieties the resistance factor found in *Solanum tuberosum andigenum* from South America. Tubers of *S. t. andigenum* have been grown in infested soil to discover what type of resistance is involved. Counts are not yet available, but it is already clear that larvae of *H. rostochiensis* penetrate the roots of this plant but mostly fail to attain maturity. (C. C. Doncaster.)

Resistance to *Heterodera major* infestation is being investigated in twenty-one varieties of barley and seventeen varieties of spring oats, in co-operation with the National Institute of Agricultural Botany and the N.A.A.S. (J. J. Hesling.)

Pathogenicity

The dynamic equilibrium which exists between a plant host and its worm parasite can be upset, under certain conditions, in the direction of plant disease, with consequent loss of yield. This situation is difficult to investigate. In *Heterodera rostochiensis* it is being approached from opposite ends. First, and more fundamentally, the biological complexity of soil as an ecological habitat could be side-tracked if bacteriologically sterile larvae could be made to invade sterile roots. Tomato roots have been successfully grown by sterile tissue-culture methods, but so far it has not been possible to produce viable sterile larvae. (D. W. Fenwick.) The end result may be disease, revealed by various symptoms. A start has been made on testing symptom-assessment in attacked potatoes with a view to finding sensitive symptoms amenable to scoring and statistical analysis. These symptoms are largely those of drought, and the past season was too wet to yield many helpful results. (B. G. Peters and A. R. Forster.)

The study of several populations of supposed *Aphelenchoides parietinus* has been started. This species is common in decaying plant material, and the problem is whether, and under what conditions, it can become pathogenic. (M. T. Franklin.)

Two other situations should be mentioned in which the rôle of eelworms in causing manifest disease is doubtful. First, the investigation of *Hoplolaimus uniformis* in Sitka spruce, in collaboration with the Chemistry Department, is being pursued, and secondly, further advice has been given to Mr. A. R. Bull of the West African Institute of Oil-palm Research on the eelworms associated with seedling oil palms suffering from a disease called " Blast ", of doubtful aetiology. (J. B. Goodey.)

Eelworm Population Changes

Heterodera rostochiensis

By arrangement with the Kirton Experimental Husbandry Farm (N.A.A.S.) annual samples are being taken from an eight-course and a five-course rotation experiment there. These rotations have been laid down by the N.A.A.S. to reduce the eelworm population, and we are following the course of its fall. At Rothamsted one complete cycle of the three-course rotation experiment has now been completed : this year's counts are not yet available. (C. C. Doncaster.)

Eelworm strains from eight localities have been used in a pot experiment to compare the multiplication rates of the strains when

cysts of differing size were used as inocula. The new cysts produced, also graded by size, and of known age, are available for future use. An experiment to test the effect on multiplication-rate of wintering cysts outside and in the laboratory, prior to using them as inocula for potatoes planted in March and May, showed that the method of wintering had no effect upon multiplication rate, but the May-planted potatoes produced more of the largest cysts, and also more tubers, than those planted in March. (J. J. Hesling.)

Heterodera major

By the kindness of Mr. P. R. J. McMorland, annual samples are being taken from his fields, near Winchester, to follow changes in the cereal root eelworm population under various rotations. At Stoke-on-Tern (Salop), with the valued co-operation of Mr. H. C. F. Newton, a micro-plot experiment has been laid down to study the rate of increase of *H. major* over several years, in the presence of both autumn- and spring-sown oats, wheat, barley and rye. (J. J. Hesling.)

Heterodera cruciferae

In a small plot on which crucifers are grown each year to find the maximum achievable level of population under field conditions, the density of eggs and larvae per g. of air-dried soil has risen from 12 to 64. (C. C. Doncaster.)

Root Diffusate Problems

Heterodera rostochiensis

Reference was made last year to the tripartite scheme for research into the chemical nature of potato (or tomato) root diffusate; this year we have continued to monitor the charcoal extraction carried out at Reading and to bio-assay numerous fractions produced by Cambridge. Results are now available on the breakdown of potato-root diffusate in sand, gravel, peat and clay; breakdown is most rapid in sand and gravel, and least rapid in peat. It is difficult to interpret the results, partly owing to the varying water capacities of these four materials. Partial soil sterilization neutralizes root diffusate for a few weeks, after which breakdown appears to be slower than in unsterilized soil. Moreover, the rate of breakdown is increased following successive applications of diffusate. So far as they go, these results suggest bacterial breakdown, whereas previous *in vitro* tests had shown that bacterial filtration did not materially delay breakdown. Further investigations are proceeding. (D. W. Fenwick and E. Widdowson.)

Root diffusates from sixteen species of Gramineae, including five cereals, collected after two and three weeks of growth, failed to stimulate hatching from *Heterodera rostochiensis* cysts. Stimulation had been observed earlier, in some of these grasses, by both M. J. Triffitt and M. T. Franklin, and accordingly the present experiment was carried out twice, with the same negative result. A preliminary comparison of diffusates from *Solanum andigenum*, potato, and *S. demissum* showed strong stimulation from all three and roughly in that order (" roughly ", because no account was taken of differential root size or growth rate). Thus, there is no *a priori*

reason why *S. andigenum* × *S. tuberosum* crosses, bred for resistance to *H. rostochiensis*, should not also produce active diffusates, which would give them a valuable trap-cropping effect. This would be a biological alternative to the manufacture and application of artificial hatching stimulants. (J. J. Hesling.)

Heterodera cruciferae

A suggested inhibiting effect of white mustard diffusate on the hatching of *Heterodera cruciferae* larvae has not been confirmed. Mixtures of mustard diffusate with those of sprouts, swedes and rape-kale gave larger hatches than any of the latter without mustard, though mustard alone was less active than sprouts alone. In the latter test some cysts were found with an external sub-crystalline layer and some with mineralized contents; in a few cases the whole cyst was solid. This occurred mainly in cysts exposed to sprouts diffusate, and not at all in those from soil leachings. The mineralized cysts are being examined spectrographically by H. H. Le Riche (Soil Survey); preliminary results are anomalous in suggesting both calcification and silicification. (C. C. Doncaster.)

Chemical Control Methods

Pot tests

Annual pot tests of nematicides in glazed pots holding 20 lb. of soil infested with *Heterodera rostochiensis* have continued. Potatoes are subsequently grown in the pots to detect phytotoxic or stimulating effects, and to show how far the eelworm population can recover after a crop.

Analysis of the 1952 results showed that six compounds based on 8-hydroxyquinoline gave disappointing results even at 10 g. per pot. Two which were water-soluble gave no kill, and in the other four, which were formulated with diacetone alcohol, any lethal effect was masked by that of the diacetone alcohol. Two of these four containing iodine had phytotoxic effects, as measured by length of potato haulms and yield of tubers.

A number of soil-fumigant tests can be briefly summarized as follows:

Probit Relationships. Using seven dosages in two-fold steps (1, 2, 4, 8, etc.), probit lines were fitted for D-D mixture and Chloro-bromo-propene. The fit was reasonably good up to above 90 per cent kill; at higher dosages there were more survivors than would be expected, suggesting that a few cysts in the soil are protected from the fumigant.

Vertical Diffusion. Using D-D to fumigate soil in wooden boxes made up from 2-inch vertical sections (so that the soil could subsequently be analysed in 2-inch layers) and lined with aluminium foil, it was found that the kill was negligibly small in the top and bottom sections exposed to ventilation. Sealing by sprinkling water on the soil surface or by covering it with a piece of aluminium foil gave only a slight improvement.

Soil Moisture. A dosage of D-D giving a 90 per cent kill in normal soil gave no detectable kill at all in air-dried soil. Additional moisture did not significantly change the kill from 90 per cent.

Field test

The co-operative experiment with Shell Chemicals Ltd. and the West Norfolk Farmers' Manure Co., to test the effects on a potato root eelworm population of single and annually-repeated D-D injections at various stages in a five-course rotation, is now in its third year. In last year's report was recorded the non-significant kill shown by the soil samples taken in spring 1952, following the first injections of autumn 1951. It is of interest to record that samples taken in autumn 1952, immediately before the second injections and twelve months after the first, showed a significant average kill of 41 per cent. The samples of spring 1953 show reasonable kills in plots injected twice, and in those injected in the first year only, but poor kills in plots injected in the second year only. It will be interesting if the latter give an improved result in the samples of autumn 1953. The whole situation suggests the novel idea that a delay of six months in taking soil samples after injection is insufficient to give a true picture of the kill. (B. G. Peters.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

Miss Pauline Smith left the department during the current year, and has been replaced by Mr. R. Bardner. Following visits by Colombo plan students to the department, Mr. Kirthisinghe of Ceylon, one of the students, arranged to work here for three months. Mr. Bernet of Switzerland is working in the department for six months.

Chemical

Physical chemistry

Particle size and toxicity of suspensions of contact insecticides. This work has been continued and very nearly completed.

In the past the toxicities of colloidal and crystalline suspensions of DDT and its analogues have been compared by dipping insects in them for a few moments. After this the insects are taken from the suspensions with poison sticking to them, and are kept for a day or more till counts of kill are made. The amounts of poison retained are not necessarily the same for different types of suspension.

Methods have been worked out for washing the poison from treated insects and chemically analysing the extracts. In this way it is possible to find out exactly how much poison is retained by the insects. Retention by adult grain beetles (*Oryzaephilus surinamensis* L.) seems to be purely mechanical, depending on the size and shape of the poison particles in the suspensions, and not on any other properties. Thus, crystals of different poisons but of the same size are retained equally well. Needle-shaped crystals are retained better than plate-shaped crystals. Poorest retention is found with plate-shaped crystals of about 25 μ; particles smaller or bigger than this are retained more efficiently. With some compounds there is no method for micro-analysis. In such a case the retention can be guessed by comparison with another compound that has analysable crystals of the same size.

The results of all comparisons of toxicity already made with compounds of the DDT type have been corrected to allow for differences in retention amongst the suspensions.

When this was done it was found that, although colloidal poison was always more toxic than the same poison in crystalline form when the insects were kept cool after treatment, the size of the difference in toxicity still varied from one DDT analogue to another.

Two qualities that might influence the size of the difference in toxicity were mentioned in last year's Report. If the crystals of a compound dissolve very slowly (compared with the deposit from the colloidal poison) in the wax of the insect cuticle, or if the colloidal suspension gives a deposit on the insects that crystallizes out slowly, the compound is likely to show a large difference in toxicity between crystals and colloid.

The corrected results of a great many tests made in the last three years have now been examined; the only compounds in the DDT series that show a large difference in toxicity between crystals and colloid are those that have *both* the above qualities. One quality or the other on its own is not enough; the reason for this is not clear.

This subject is reviewed in a special article on page 176.

Temperature coefficients of kill by volatile solid insecticides. The temperature at which insects are kept after treatment is important in deciding the kill. With contact poisons, lower temperatures after treatment often give higher kills, i.e., the temperature coefficient of kill is often negative. With commercial insect fumigants lower temperatures of exposure sometimes give higher kills, but this is unusual.

Three volatile solid insecticides (DFDT, γ-BHC and aldrin) were tested against two species of grain beetle (*Oryzaephilus surinamensis* L. and *Tribolium castaneum* Hbst.) at two exposure temperatures (30° C. and 11° C.) in simple laboratory fumigation tests. DFDT killed both species faster at 11° C. than 30° C.; γ-BHC killed *O. surinamensis* faster at 11° C. than 30° C., but *T. castaneum* faster at 30° C. than 11° C.; aldrin killed both species faster at 30° C. than 11° C.

Biochemical

The investigation on insect esterases and their inhibition by organo-phosphorus compounds has been continued by K. A. Lord and C. Potter, with the assistance of D. Holbrook. The comparison of the relative toxicities of para-oxon, TEPP, parathion and two of its analogues, reported last year, has been completed. The inhibitor power of the five poisons has been determined on choline esterase and a general esterase that does not hydrolyse acetyl choline derived from each of the four species of insects *Blatella germanica* L. adults, *Tenebrio molitor* L. adults, *Dysdercus fasciatus* Sign. adult males and *Tribolium castaneum* Hbst. adults used in the toxicity tests.

In general, the poisons are more active inhibitors of the enzyme which does not hydrolyse acetyl choline, although this is not so in every case. The inhibition data suggests that both kinds of esterase differ from species to species. This work is being prepared for publication.

Work is now in progress on the variations in amount and behaviour of esterases on different instars and species of insects. A short publication on this subject has already been made. In addition, an attempt is being made to determine the location of the esterases in the insect tissues, and techniques are being investigated for isolation of the esterases from insect extracts and studying their properties. This work is intended to provide a basis for the study of the *in vivo* action of organo-phosphorus compounds.

In connection with the studies on the action of systemic insecticides on bees and on the use of systemic insecticides to control aphids on sugar beet, a little work has been done on the behaviour and action of organo-phosphorus compounds within the plant. This work may be extended.

Organic chemistry

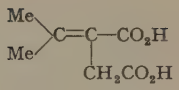
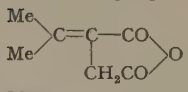
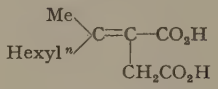
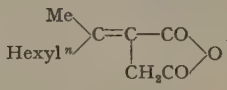
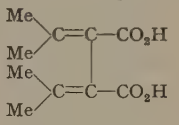
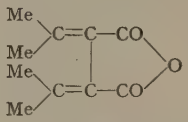
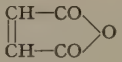
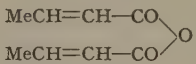
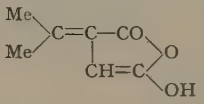
M. Elliott and P. H. Needham are continuing the work on the relationship between the insecticidal activity and the chemical constitution of pyrethrin-like compounds, and a publication is in preparation. In connection with this work two new routes to biologically active compounds of the pyrethrin type are being developed. It is hoped that it may be possible to produce toxic compounds more easily by these routes than those at present available, but the work is not sufficiently far advanced to give details at present.

In the course of this work some pure organic chemistry of general interest was carried out, of which a short account is given below.

Ultra-violet absorption of unsaturated compounds related to succinic anhydride. In the Report for 1951 (p. 117) it was stated that *iso*-alkylidene succinic anhydrides show maximum absorption at 2,350 Å. (ethanol), whereas the corresponding acids have $\lambda_{max.}$ 2,200 Å. (ethanol). The table below shows the ultra-violet absorption maxima of compounds selected to investigate this phenomenon. Since crotonic acid ($\lambda_{max.}$ 2,130 Å.) and crotonic anhydride (VIII) absorb at the same wavelength, it is improbable that conjugation is transmitted through the anhydride (—O—) oxygen in the latter compound and, therefore, in compounds (II), (IV), (VI) and (VII); moreover, $\lambda_{max.}$ for the system MeCH=CH·COR is the same whether R be (—OH) or (—O—). Again, maleic acid and maleic anhydride (VII) have almost the same $\lambda_{max.}$, indicating that an endocyclic double bond does not produce a bathochromic shift in the anhydride. To eliminate the possibility that an enolic structure, (IX), might contribute to the absorption spectrum of (II), the infra-red spectra of (II) and of (VI), which could not enolize, were compared (gratitude is expressed to Dr. L. Crombie of the Organic Chemistry Department, Imperial College of Science and Technology, for these measurements), but no bands in the hydroxyl region were found with either compound. Woodward (*J. Amer. chem. Soc.*, 1942, **64**, 76), collected data to show that αβ-unsaturated ketones with exocyclic double bonds had maxima nearer the red than corresponding compounds without exocyclic double bonds. It appears, therefore, that an exocyclic double bond conjugated with the carbonyl group of an anhydride also exerts a bathochromic effect in comparison with related αβ-unsaturated acids and anhydrides without exocyclic double bonds.

The ultra-violet absorption spectrum of a fulgide such as (VI) has not been previously determined. The very broad absorption band ($\lambda_{max.}$ 2,760 Å.) is obviously related to the phototropic properties of the fulgides with phenyl and other aromatic substituents.

The constituents of pyrethrum flowers. Work on separation of the constituents of extract or pyrethrum flowers has been continued. The technique of displacement chromatography has been applied to the problem, and by its use J. Ward has separated the four known active constituents from each other and from some inactive constituents of pyrethrum extract. The separation was achieved by adsorbing the pyrethrins on activated alumina and eluting with a solution of stearic acid in normal hexane. A note on the process has been published. Later work was directed to achieving a separation on a larger scale. Difficulties were encountered in scaling up

Compound	Structure	$\lambda_{max.}$ (Å.)	$\epsilon_{max.}$
I. *iso*Propylidene succinic acid		2,210	9,400
II. *iso*Propylidene succinic anhydride		2,350	12,500
III. γ-Hexyl γ-methyl itaconic acid		2,250	8,730 (methanol)
IV. γ-Hexyl γ-methyl itaconic anhydride		2,350	12,600
V. Tetramethyl fulgic acid		2,200	15,000
VI. Tetramethyl fulgide		2,190 2,760	12,110 11,500
VII. Maleic anhydride		2,130 2,130	8,900 (ethanol) 10,300 (hexane)
VIII. Crotonic anhydride		2,140	23,400 (hexane)
IX.		—	—

the process, but about 100 mg. of cinerin I and 300 mg. of pyrethrin I have now been obtained. Certain physical constants of these materials have been measured and their dinitrophenylhydrazones prepared. An automatic fraction collector is being built, and the chromatographic work will be continued as soon as this is completed. A rough assessment of the biological activity of these four compounds to mustard beetles, *Phaedon cochleariae* Fab., has been made by P. H. Needham. Their relative toxicities were as follows :

	LD 50% w/v	Relative potency
Cinerin I	0·0020	10,00
Pyrethrin I	0·0010	2,000
Cinerin II	0·0050	400
Pyrethrin II	0·0026	769
Allethrin	0·0250	80

Biological

Pyrethrum

(*a*) In addition to the work already described on this subject, members of the department have taken part in a collaborative study on the insecticidal activity of strains of pyrethrum. This work is in preparation for publication.

An estimation of the activity of a strain of flower collected from Aden has been made by P. H. Needham at the request of the Colonial Products Advisory Bureau, with results as follows :

Proportions of Pyrethrin I and Pyrethrin II in sample treated

	%
Extract of flowers from Aden	
Pyrethrin I	0·35 w/v
Pyrethrin II	0·16 w/v.
Total pyrethrins	0·51 w/v.
Extract supplied by Cooper Technical Bureau	
Pyrethrin I	13·67 w/v.
Pyrethrin II	10·99 w/v.
Total pyrethrins	24·66 w/v.

Relative toxicities against Tenebrio molitor

	Measured drop, %	Injection, %
Aden extract	0·100	0·120
Cooper's extract	0·122	0·130
Allethrin	0·950	0·480

Concentrations of total pyrethrins required to give 50 per cent kill.

(*b*) A study of synergism of the pyrethrins has been started by C. Potter, K. A. Lord and D. Holbrook. The object of this work is to investigate some of the biological and physico-chemical factors that influence synergistic action and at the same time to obtain detailed information on the performance of some particular synergists with the pyrethrins. So far, performance curves have been obtained for the synergistic action of piperonyl butoxide (technical material containing 80 per cent of 3 : 4-methylenedioxy-6-propylbenzyl (butyl) diethylene glycol ether) and Sulphoxide (*n*-octyl sulphoxide of *iso*safrole) under one set of experimental conditions using *Tenebrio molitor* L. adults as test subjects and preliminary data using *Blatella germanica* L. adults and *Phaedon cochleariae* Fab. adults.

Investigations were also carried out on the synergistic properties of *Melaleuca bracteata* Nuell. oil sent to us from Kenya by Mr. Gilbert Walker, and a performance curve has been obtained, using *T. molitor* adults as the test insect. Further investigations are to be carried out on *B. germanica* and *P. cochleariae* when these insects become available.

Bioassay techniques

Measured drop and injection technique. The range of application of the micrometer syringe used for these bio-assay techniques has been increased by a modification permitting the rapid reproduction of doses down to 0·000125 ml., utilizing the clicking device

described last year. A variety of media can be employed with this apparatus, including water, odourless distillate and acetone.

The use of the 0·000125-ml. drop enabled the aphid *Megoura viciae* Buckt, to be added to the list of suitable test insects.

Film method for contact poisons on glass-climbing insects. Contact insecticides are often tested by a film method : a surface such as paper is sprayed with an insecticidal preparation and then allowed to dry, giving an even film on the surface. Insects are allowed to run on the treated surface. This method is suitable for flat surfaces and for insects that cannot climb the smooth vertical surfaces that are often used to contain them on the film.

During the course of his work on particle size effects, A. H. McIntosh had occasion to compare a number of contact poisons as residual films, and he and Mrs. Macfarlane developed a technique for this purpose which can be used with species of insect that can climb smooth surfaces. The technique is also of general application.

An even film of insecticide is made on a 9-cm. circle of filter-paper. When the paper is dry, it is folded loosely in half and the edges fastened together with an Emgee " Multigrip " rotary paper crimper. A small opening is left at one end. Through this the insects are inserted into the paper, by way of a glass funnel if necessary. Fifty adult *Oryzaephilus surinamensis* L. are used for each paper. The opening is closed by crimping, and the paper is stored at constant temperature. The insects are quite unable to crawl off the treated surface. The method is simple to use. The papers do not take up much constant-temperature space; they can be stored flat or upright. Repeated cleaning of glassware is unnecessary. If more than one count of kill is needed, the paper can be opened and crimped again several times.

The effect of bio-assay technique on relative toxicity. During some recent routine bio-assay tests on some extracts of different strains of pyrethrum flowers, for the Colonial Products Advisory Bureau, in which " allethrin " was used as a standard reference insecticide, an interesting point arose concerning the difference in relative toxicity of allethrin and natural pyrethrins when injected and applied topically.

This is now being investigated more fully, and a note on it will be published in the near future.

Bio-assay of phosphorus insecticides. Since organo-phosphorus compounds are being extensively used in the departmental field experiments, it seemed desirable to have detailed information on their insecticidal action. A series of laboratory tests have therefore been started to investigate the relative importance of the contact, stomach poison and fumigant activity of a series of organo-phosphorus insecticides with systemic action including " Systox ", " iso-Systox ", schradan, " N.C.7 " and parathion.

The contact activity of these poisons has been investigated against *Phaedon cochleariae* F. and *Megoura viciae* Buckt., and it is intended to add also *Alphitobius laevigatus* F. and *Diataraxia oleracea* L. larvae.

The investigation of all three factors will be made against *Diataraxia oleracea* L. larvae with which a start has been made on stomach-poison tests.

If a suitable technique can be arranged for *feeding* known doses

of poison to an aphid, *Megoura viciae* Buckt, will be included in the stomach-poison tests.

Toxicity and persistence of insecticidal deposits

Work on this subject was continued by J. Ward and P. E. Burt during the first half of the year. Thereafter the entomological side of the work was taken over by M. J. Way and E. M. Gillham.

Microscopical techniques were investigated in order to find a method of observing the very small crystals of DDT which have been used. It was found that the most satisfactory method was to mount them in glycerol or water and view them with dark ground illumination. In this way it is possible to follow the evaporation of the crystals on slides stored for different periods.

The deposits formed when various types of emulsion are sprayed were studied. It was found that an emulsion of 25 per cent re-crystallized DDT in xylene gave a deposit with crystals of about the same size as those in the suspensions previously used. The crystals appeared over a period of about 6 hours from the time of spraying. The toxicity of these deposits to *Tribolium castaneum* Hbst., on both glass and leaves, was of the same order as that of deposits from suspensions and the rate at which toxicity decreased when the deposits were exposed in a glass-house was also about the same.

The work described in the Annual Report for 1952 had suggested that the main cause of loss of toxicity of DDT deposits under our experimental conditions was volatilization of the DDT. Further evidence that this was so was obtained by exposing sprayed plates in a still atmosphere and in a draught from an electric fan. It was found that the plates in moving air lost their DDT more than twice as rapidly as those in still air. An attempt was made to reduce the rate of evaporation of DDT by mixing it with a resin. An emulsion was made of a solution in xylene of equal weights of DDT and of "Arochlor 5460", a chlorinated polyphenyl resin. This formulation produced a deposit consisting of droplets of a viscous liquid which did not crystallize even after several weeks. On exposure to high temperatures and to sunlight, however, DDT was lost at least as rapidly as from crystalline deposits. It is thought that a mixture containing a larger proportion of resin may prove more successful, and this will be tested in due course.

The mechanism of selection of strains of insect resistant to insecticides

F. Tattersfield and J. Kerridge have continued their work on this subject. Two papers giving an account of work carried out in previous years have been published in the *Annals of Applied Biology*. A number of issues arising out of previous work have been examined.

Problems arising from the CO_2-sensitivity of the strain of *Brosophila melanogaster* Meig. used have been investigated.

(*a*) A preliminary series of tests showed that these insects could be "conditioned", i.e., by administering sub-lethal doses of CO_2, the insect for a period showed an increased resistance to the toxic effects of this gas.

A more elaborate experiment on a stock of insects which, however, were not of the highest susceptibility, in which successive increases in concentrations of CO_2 were administered at 24-hour intervals for four days showed on statistical analysis that the average proportion surviving was significantly greater than in the case of fresh insects. M. J. R. Healy of the Statistical Department confirmed this finding by the use of a more rigorous analysis. Certain other points emerging from our analyses, and those of M. J. R. Healy, will need further investigation.

(*b*) A series of respiration experiments with strains of *D. melanogaster* sensitive and non-sensitive to CO_2 at temperatures of approximately 15° C. have not indicated any difference between them in rate of respiration of sufficient significance to account for their marked differences in sensitivity to CO_2. The investigation, however, showed up grave imperfections in the several techniques employed.

Tests were undertaken to ascertain whether *D. melanogaster* could be " conditioned " to the effects of insecticides. The work is in progress, and data obtained by the application of DDT and BHC to the adults are being examined. So far, the results do not indicate that such is the case.

We are being compelled to undertake experiments on the effects of certain environmental factors such as food, etc., upon the viability of *D. melanogaster* adults and on their resistance to DDT. Preliminary investigations have shown that some of these factors are of considerable importance, and it is proposed to extend the investigations.

At Professor L'Héritier's suggestion we undertook during the autumn to examine *Drosophila melanogaster* Meig. captured in different localities to ascertain how widespread was their susceptibility to CO_2. Dr. H. Kalmus, of the Galton Laboratory, who kindly undertook to arrange the trapping, and Miss J. Kerridge have found that such sensitivity is widespread with this insect, confirming results obtained by Professor L'Héritier.

Insect rearing

Fourteen species of plant-feeding insects and eleven species of stored-products insects were reared during the year. Four species were added to the previous year's list: the " Khapra " beetle, *Trogoderma granarium* Everts.; the willow aphid, *Tuberolachnus saligna* Gmel.; the ladybird beetle, *Coccinella septempunctata* F.; and the wheat bulb fly, *Leptohylemyia coarctata* Fall. *C. septempunctata* is being reared in connection with the field experiments on the pests of field beans, and the wheat bulb fly is being reared in order to provide material for insecticide tests on the control of the insect.

J. Kenten has continued her work on the factors influencing the production of the various forms of the aphid *Acyrthosiphon pisum* (Harris), and has made observations throughout the year on an unidentified species of *Phaenobremia* (Cecidomyidae) which causes considerable damage to the laboratory cultures of the aphid *Macrosiphoniella sanborni* Gill. The following is a short progress report on the observations and experiments on the biology

of the four species (a) *Cocinella septempunctata* F., (*b*) *Phaenobremia* sp., (*c*) *Acyrthosiphon pisum* Harris, (*d*) *Leptohylemyia coarctata* Fall. :

(*a*) *Coccinella septempunctata* F. An attempt was made to rear *Coccinella septempunctata* F. in the laboratory for use as a test insect for the study of insecticidal action. It was found difficult, however, to rear the large numbers that would be required for this purpose owing to the large quantities of aphids necessary for food. It was also found that the adults were very erratic in their egg-laying habits when kept under greenhouse conditions, which suggests that it might be difficult to ensure an all-the-year-round supply. However, P. Forbes has been able to rear a series of six generations throughout the year by keeping some insects at constant temperatures of 20° C. and 24° C. and under continuous illumination. It is considered therefore that should this insect be required it could, if necessary, be reared in moderate numbers throughout the year, but that it would not be practical to rear it as a test insect for general purposes.

(*b*) *Phaenobremia* sp. Observations have been made throughout the year on an unidentified species of *Phaenobremia* (Cecidomyidae), a predator of the aphid *Macrosiphoniella sanborni* (Gillette), which causes considerable damage to the laboratory cultures of this aphid. The midge larvae were first observed attacking the aphid culture during May, and from an initial stock of about twenty larvae, five generations of midges were reared in the laboratory, the last midges emerging during October. A complete life cycle took from four to five weeks, of which (very approximately) the egg stage took four to five days, the larval stage eight to fifteen days, pupal stage thirteen to sixteen days. The length of life of the adults was very variable (probably due to an imperfect rearing technique) and many died after one to two days ; a number, however, lived from fourteen to seventeen days, and on one occasion an unfertilized female lived for twenty-three days. This particular female was dissected after death and found to contain 116 fully developed eggs. No larvae was ever obtained from unfertilized females.

It was not found possible to induce midges to lay their eggs on bean plants bearing aphids *Acyrthosiphon pisum* Harris or *Aulacorthum circumflexus* Buckton. They would, however, lay their eggs on chrysanthemum leaves bearing no aphids, and on cotton-wool strands, and the resulting larvae fed readily on *A. pisum* and *A. circumflexus*, and in both cases adult midges were obtained.

(*c*) *Acrythosiphon pisum* Harris. Experiments to test the effect of different photoperiods and temperatures on the reproduction and production of various forms of the aphid *A. pisum* have been discontinued. It was found that this aphid will readily produce sexual forms at temperatures below 20° C., if parent apterae are given a daily photoperiod of 8 hours during the period from birth until the last imaginal moult. If, however, parent apterae received a daily photoperiod of 16 hours during this period they produced only parthenogenetic forms. In both instances the treatment the parent aphids received after their last imaginal moult had no effect on the proportion of sexual offspring they produced. The temperature which favoured the optimum production of males differed from that which favoured the optimum production of females. The largest numbers of male offspring were obtained at 19–20° C. (20–30 per

cent), of females at 11–13° C. (50–80 per cent). No sexual forms were obtained at temperatures above 25–26° C.

The length of life of the aphids increased with decrease in temperature from approximately twenty-two days at 29–30° C. to approximately 140 days at 5–9° C. Maximum reproduction occurred at 19–20° C., where an average of seventy-seven to eighty-six offspring were produced per parent. Above and below this temperature the reproduction dropped to none to sixteen per parent at 29–30° C. and twenty to thirty-four per parent at 5–9° C. The offspring produced by aphids kept at 29–30° C. from birth were abnormal, in that their nymphal period was frequently prolonged and that when mature they were considerably smaller than was usual.

(*d*) *Leptohylemyia coarctata* Fall. An attempt is being made to rear *Leptohylemyia coarctata* Fall., the wheat bulb fly, in the laboratory on a large scale. Pupae were obtained from Dr. H. C. Gough of the National Agricultural Advisory Service, Cambridge, shortly before the flies emerged at the beginning of June; of these approximately 50 per cent produced adult flies. These flies were kept in the laboratory under a variety of temperature conditions in two types of cages, muslin-covered cages (2 feet × 2 feet × 2 feet) and in cages made from hurricane lamp-glasses. The majority of the flies received a diet of three foods: honey, condensed milk and blood, a number, however, were given other diets, i.e., Bovril and honey, Bovril and condensed milk, condensed milk and honey, blood and honey, honey, blood; these flies were kept in lamp-glass cages. Egg-laying commenced at the beginning of July, and continued, in some instances, until October. The eggs were collected every two to three days and counted. It was found that the flies in the lamp-glass cages receiving a diet of the three foods (honey, condensed milk and blood) produced many more eggs than either the flies kept in the large muslin cages receiving the three foods or the flies kept in the lamp-glass cages receiving the other diets, i.e.:

Eggs per female	
115–242	for flies in lamp-glass cages fed on three foods
0–19	for flies in lamp-glass cages fed on other diets
10–35 (approx.)	for flies in muslin cages fed on three foods

The eggs obtained from these flies and from other flies caught in the field, were placed at a number of conditions of humidity and temperature to find the conditions necessary for optimum survival. So far, it has been found that at temperatures of 20° C. and above the eggs soon become infected with mould, and at 30° C. the eggs did not develop at all. At relative humidities of 96 per cent and below (at 20° C.) eggs became desiccated and collapsed. Some of the eggs are receiving a variety of temperature treatments in an attempt to break the diapause of the egg.

The effect of plant-protective chemicals on pollinating insects

D. Glynne Jones and J. Connell have continued their work on this subject at Seale-Hayne Agricultural College. The bio-assay of various chemicals has been continued, and those tested include

melathon, " Pyrolan ", endrin, " Systox " and " N.C.7 " (Peat Control Ltd.). The results may be summarized as follows :

Stomach poison	mg./bee
Malathon (LD50/24 hours)	$31{\cdot}6 \times 10^{-5}$
" Pyrolan "	$137{\cdot}6 \times 10^{-5}$
Endrin	$141{\cdot}3 \times 10^{-5}$
" Systox " (active ingredient)	$147{\cdot}8 \times 10^{-5}$
" N.C.7 "	$359{\cdot}3 \times 10^{-5}$

Contact poison	mg./sq. cm.
Malathon (LD50/24 hours)	$107{\cdot}2 \times 10^{-5}$
" Pyrolan "	$454{\cdot}3 \times 10^{-5}$
Endrin	$495{\cdot}7 \times 10^{-5}$
" Systox " (active ingredient)	$512{\cdot}3 \times 10^{-5}$
" N.C.7 "	$1230{\cdot}0 \times 10^{-5}$

No fumigant or residual contact effect is to be expected when these chemicals are used at normal field concentrations.

The possibility of the active ingredient of " Systox " contaminating nectar following foliar applications has been investigated using radio-tracer techniques in collaboration with Dr. Thomas of the Long Ashton Research Station. The rate of translocation from treated to untreated leaves was shown to be much slower than for schradan, and the amounts appearing in nectar are very small. The investigations into the action of dusts on the waterproofing mechanism of the honeybee and other adult hymenoptera has been continued, and are now being prepared for publication.

Evidence has been offered to the Zuckerman Working Party considering the effect of toxic chemicals on wild life.

Field Experiments

Control of Aphis fabae *on field beans*

M. J. Way assisted by P. H. Needham continued the work on this subject. As a continuation of the 1950–52 trials, an account of which has been sent in for publication, a more ambitious experiment was laid down to compare parathion, " Systox " and DDT sprays for control of bean aphid, *Aphis fabae* Scop., on field beans. Replicated plots of spring and autumn sown beans were planted, and tractor-drawn farm spraying machinery was used to apply the the insecticides. Unfortunately the aphid infestation did not develop. Only one insecticide treatment was applied, and this showed that the spraying machinery, comprising a spray boom with drop bars, gave satisfactory coverage of the crop. The experiment is to be repeated during 1954.

A small-scale replica of the main field trial was laid out on the Garden Plots. Shrubs of spindlewood, the winter host of *A. fabae*, were planted near by. These were attacked by the aphid, and from them many alatae migrated to the beans during June. However, due to the cold, wet weather, aphid colonies did not build up, and counts of flower, pod and seed production on sprayed and unsprayed plots showed that the aphis attack had no effect on development of autumn sown, and little effect on the spring sown, beans.

In three small field trials at Woburn and at Rothamsted bean

aphis control was attempted with seed and soil treatments of the systemic insecticide "Systox". The insecticide was applied as seed dressings or as a soil treatment in the seed drill at the time of planting in early March. The seed dressings, which comprised relatively low doses of "Systox", had no recognizable effect on the small aphid attack which developed in June and July, but the soil treatment kept the crop practically free of aphids until it was harvested in August. It is interesting that all treatments were toxic to the adult pea and bean weevil, *Sitona lineata* Linn., and markedly reduced feeding damage by this insect during May.

Effect of insecticides on the aphid–parasite–predator complex

In conjunction with the Entomology Department a preliminary attempt was made to assess the importance of certain aphid parasites and predators in reducing aphid populations on field beans and on a brassica crop. Laboratory experiments showed that 0·3 per cent w/v. calcium arsenate sprayed on aphid infested cabbages and field beans had little effect on *Myzus persicae* Sulz. and no effect on *Aphis fabae* Scop. The insecticide was, however, toxic to Braconid parasite adults and to Coccinellidae, especially the larvae. In view of this selective effect the insecticide was used to treat small plots of beans and cauliflowers at fortnightly intervals from the beginning of June. Predators were relatively scarce, and no Braconid parasites were recorded on the beans. The insecticide reduced the Coccinellid population almost to zero, but appeared to have little effect on Syrphid larvae. The *A. fabae* population rose higher than that of the untreated control plants, but the experiment was spoilt by severe phytotoxicity caused by the calcium arsenate during humid conditions in July. This phytotoxicity had not shown up in the laboratory trials.

On the cauliflowers a few colonies of *Brevicoryne brassicae* Linn. and *M. persicae* were recorded, but in both treated and control plots the numbers fell almost to zero in September, after reaching a peak of around fifty per plant in July. Occasional Coccinellid adults, Syrphid larvae and Braconid parasites were recorded on clusters of *B. brassicae*. No Coccinellid eggs or larvae were found. It seemed that unfavourable weather was responsible for the scarcity of aphids, which never became sufficiently abundant to attract significant numbers of parasites or predators.

Wheat bulb fly

Field trials on the protection of wheat against wheat bulb fly (*Leptohylemyia coarctata* Fall.) by the use of insecticides have had little success so far. M. J. Way and R. Bardner have started work on this problem. The most promising method would seem to be the control of the newly-hatched larvae at the stage where they enter the wheat seedling. To gain further information under more closely controlled conditions than hitherto, a small-scale experiment is in progress, using wheat planted in seed-boxes. Known numbers of eggs, obtained from flies kept in the laboratory, have been placed in the boxes, and the efficacy of several insecticides in various formulations in reducing the number of infested plants is being tested. For any treatment to be practical economically,

the insecticide would probably have to be applied at the time of sowing in the autumn to control larvae which hatch in early February, and preliminary experiments on the effective persistence of soil insecticides for this length of time are being carried out. The possibility that soil insecticides might have an appreciable ovicidal action on the eggs is also being investigated. The rate of progress of the above experiments could be much greater if satisfactory methods of breeding the flies all the year round in the laboratory can be devised, and the work on this subject is described in the section on insect rearing.

Some work is being done on the structure and properties of the egg-shell, which may be of use in connection with survival in the field and the action of ovicides. Histological work is also being done in connection with the experiments on diapausing eggs.

Control of the vectors of potato virus

P. E. Burt of this department, in conjunction with L. Broadbent of the Plant Pathology Department, continued the experiments on the control of virus diseases of potatoes.

In 1951–52 an experiment was carried out in which plots of potatoes, each containing some plants infected with leaf roll and some with virus Y, were sprayed with various insecticides in an attempt to control the aphid populations and to prevent the spread of the virus diseases through the crop. The results of these experiments (see Annual Report 1952, p, 87) were encouraging, and a further experiment on similar lines was carried out in 1953.

The treatments used were a DDT suspension, and emulsions of DDT, endrin, malathon and " Systox ". Nine applications were made during the period 29th May 1953 to 4th September 1953. Modifications were made to the spraying machine used in the 1951–52 experiment according to a specification drawn up jointly by the department and the manufacturers. This has enabled much better crop coverage to be obtained, especially on the undersides of leaves. There was a very high aphid population in the control plots in July, which was effectively reduced by all the treatments, " Systox " and endrin being most effective. For example, the total aphids count on 23rd July on 120 leaves was 3,929 in the control plots, eight in the endrin treated plots and none in the " Systox " treated plots.

An estimate of the amount of virus spread will not be available until next year. Further information on this series of experiments on virus control is given in the report of the Plant Pathology Department.

Control of wireworms

The experiments started in the autumn of 1951, in collaboration with F. Raw of the Entomology Department, on the direct and residual effects of a number of insecticides on wireworms have produced interesting results. Large differences in the residual effects of the different treatments are apparent in this, the second year after treatment. The following figures have been obtained for the yields in autumn 1953 :

Yield of grain in cwt./acre, Autumn 1953

Treatments Autumn 1951 :	Untreated	S	G	A	C	D	Mean
Mean (± 1·60) ..	21·6 *	22·9	30·2	34·6	32·9	26·7	26·5
Increase (± 1·84)	—	1·3	8·6	13·0	11·3	5·1	—

* ± 0·92.

S = BHC seed dressing at 2 oz. per bushel of the dressing.
G = 3·5 per cent BHC dust combine drilled with seed at 56 lb./acre.
A = 1·78 per cent aldrin dust combine drilled with the seed at 200 lb./acre.
C = 5 per cent chlordane dust combined drilled with the seed at 100 lb./acre.
D = 5 per cent D.D.T. dust combine drilled with the seed at 150 lb./acre.

These figures show a good correlation with the figures for wireworm population estimated by F. Raw, and the comparison is given in the report of the Entomology Department. The crops on the control plots and those originally treated with dressed seed are probably not economic, while on the plots where the insecticides were drilled in with the seed there has been a marked crop increase, good crops being obtained with BHC, aldrin and chlordane.

ENTOMOLOGY DEPARTMENT

C. B. Williams

Staff

During the year J. E. Satchell and M. M. Hosni have left, and R. M. Dobson has joined the staff.

M. M. Hosni obtained the degree of Ph.D. at London University for a thesis on the effect of environmental conditions on populations of insects.

B. R. Laurence (now at Birkbeck College) obtained the degree of Ph. D. London for work done at Rothamsted on the insect fauna of dung.

C. J. Banks obtained the degree of Ph.D. at the University of London for a thesis on the effect of predators, particularly Coccinellidae and Syrphidae, on populations of the black bean aphis (*Aphis fabae*).

D. B. Long obtained the degree of Ph.D. at the University of London for a thesis on the effect of population density on the physiology and behaviour of lepidopterous larvae.

P. W. Murphy obtained the degree of D.Phil. at Oxford University for a thesis on the rôle of certain insects and mites in determining the fertility of forest soils.

Dr. K. K. Nayar, senior lecturer in the Department of Zoology, University College, Trivandrum, who has been on study leave for one year for advanced post-doctoral work and training, spent most of the summer here working on gall midges before going to Leeds, Oxford and Cambridge Universities.

Dr. Raw attended the 14th International Congress of Zoology in Copenhagen and read two papers—" The extraction of small arthropods from soil samples by a flotation method " and " The abundance of Protura in grassland ". Summaries of these will be published in the *Proceedings* of the meeting.

Effect of Weather Conditions on Insects

(C. B. Williams, R. A. French, M. M. Hosni and Samira El-Ziady)

The continuous trapping of insects by light traps was brought to a conclusion in March 1953 and the results included in a thesis by M. M. Hosni. During the summer a detailed experiment was carried out to test the differences between two types of light traps (the Rothamsted and the Robinson) and two types of illumination (ordinary electric light and a mercury vapour bulb) for different orders of insects. The mercury vapour lamp, rich in ultra-violet light, was two to three times as attractive as ordinary light for all groups of insects. The Robinson trap was definitely more efficient than the original Rothamsted type for larger insects such as the Macrolepidoptera, but much less efficient for the Diptera, which are mostly small or very small insects.

Miss Ziady has continued her study of the population of flying insects at 5 feet and at 30 feet by means of suction traps, and the

results of the past two years' work are now being studied; there is new evidence of a lunar periodicity of catches in the suction traps.

Insect Migration

(C. B. Williams and R. A. French)

The most important work during this year was the planning and carrying out of a short expedition to the Pyrenees in September and October to study the autumn southward movement of insects that had recently been observed in this area. C. B. Williams and R. A. French, with several voluntary assistants, took observations at various localities from the Mediterranean coast to over 9,000 feet in the Gavarnie area over a period of nearly six weeks, and southward movements of insects were seen on almost every fine day. The insects included about ten species of Lepidoptera and four species of Diptera (with others in smaller numbers), but very few dragonflies were seen. Among the Lepidoptera were large numbers of the small cabbage white (*Pieris rapae*) and the silver Y moth (*Plusia gamma*), both crop pests in Britain and Central Europe. Among the Diptera were two species of hoverflies (Syrphidae), one a well-known predator on Aphididae.

These results are of importance from the economic point of view, and also from the scientific angle, as they demonstrate the reality of the to-and-fro movement of great numbers of species and individuals of insects to the north in the spring and to the south in the autumn, much more resembling the migrations of birds than has been previously accepted.

We wish to acknowledge the receipt of a grant from the New York Zoological Society, which helped to defray the costs of this work.

Effects of Population Density on Insects

(D. B. Long)

Further experiments have been carried out involving the effects of population density on lepidopterous larvae. The faster rate of development occurring in crowded cultures when compared with their solitary controls is of particular interest. Associations of as small a number as two larvae of *Plusia gamma* can result in a marked increase in the growth rate of the individuals. The egg-laying habits of the adults are of prime importance amongst the factors governing larval associations. Eggs which are laid in loose or tight clusters, such as those of *P. gamma* and *Pieris brassicae*, afford suitable conditions for subsequent larval association, and may be contrasted with eggs which are laid singly or in occasional pairs. The larval association of *P. brassicae* typifies one class of association in which the larvae form dense masses, whilst the larvae of *P. gamma* illustrate the other class, in which the larvae are more dispersed though still retaining a loose association.

A study has been made, both in the laboratory and in the field, of some of the factors responsible for the formation and maintenance of larval associations. The silk-spinning habit of the larvae of *P. brassicae* assists their aggregation, whilst strong gregarious tendencies result in the maintenance of the association

and the development of a mass feeding and resting rhythm. The presence of this rhythm in crowded cultures is probably largely responsible for the marked difference in the rates of development occurring between crowded and solitary cultures. The gregarious tendency is weakened by conditions of prolonged isolation.

The larvae of *P. gamma* are only slightly gregarious. Larval aggregation is built up and maintained by the reaction to larval proximity which induces feeding. This reaction appears to be more developed in crowded cultures. Under crowded conditions in the field the larvae show little tendency to disperse until the food plant is completely defoliated. It had previously been observed that a darkening of larval colour occurred in crowded cultures only, and it has now been found that this darkening is dependent on a sense of contact between larvae, and therefore also involves the question of larval proximity.

Gall Midges of Economic Importance

(H. F. Barnes, Barbara M. Stokes, K. K. Nayar and G. W. Heath)

The twenty-seventh successive annual sampling of the wheat on Broadbalk showed that the numbers of larvae of the wheat blossom midges in 1953 remained at about the same level as in 1952, in spite of the fact that ten times as many *Sitodiplosis mosellana* emerged from the 1941–51 samples of larvae in 1953 as in 1952. However, the ratio of midges to parasites indicated that an increase may be expected in 1954.

A good start has been made to an investigation into the biology and host plant range of the *Mayetiola* species recorded as attacking the lower part of the stems of cereals and grasses. A species obtained from *Agropyron repens* has already been reared successfully on several different plants, including various species of *Triticum* and also on barley and rye. Tests are also in progress on the host plant range of *Mayetiola dactylidis*.

Improved techniques to ascertain the incidence of various grass-seed midges have also been evolved, while preparations have been made to carry out control experiments in the coming year at the Grassland Research Station, Hurley.

A successful start has been made in the study of the Lucerne Leaf Midge (*Jaapiella medicaginis*) by the development of a sampling technique to ascertain its prevalence in commercial stands of lucerne.

The biology of the black medick or " Trefoil " gall midge (*Dasyneura lupulinae*) has been worked out, and tests have been made to see if it would attack lucerne. These latter experiments gave negative results in every case.

It has been demonstrated by inter-mating and breeding experiments that the Shasta daisy midge (*Contarinia chrysanthemi*) is the same species as that which occurs on wild ox-eye daisy, and that it will breed on *Chrysanthemum carinatum* and *C. frutescens*. It has also been shown that the *Dasyneura* species recently discovered in wild ox-eye daisy flowers will breed on commercial Esther Read. The survey of the distribution of the gall midges of wild ox-eye daisy flowers has been extended to include those of cultivated

Chrysanthemum species, as well as those in the National Chrysanthemum Species Collection at Wisley and Dr. G. J. Dowrick's collection at Bayfordbury. In this way, in addition to obtaining further information regarding the distribution of the three previously found primary species, a fourth primary gall midge has been discovered.

Further tests have been carried out on the host-plant range among violets and pansies of the two species *Dasyneura affinis* and *D. violae.*

New gall midges have been described from the Jew's ear fungus (*Auricularia auricula-judae*) found in Buckinghamshire by Professor P. A. Buxton, and from lavender, the latter midge was reared in the south of France by Dr. R. Pussard and is closely related to the raspberry cane midge. Two other new gall midges have been described from *Coprosma* (Rubiaceae); they were reared by Mr. K. P. Lamb in New Zealand.

Among the numerous gall midges that have been received for identification, perhaps the most interesting ones have been several reared from Myxomycetes by Professor P. A. Buxton. The most important are undoubtedly the Sorghum Midge and other gall midges reared from various *Sorghum* species, *Panicum* and *Eleusine* in Uganda, Gambia and Nigeria. The possibility of carrying out biological studies on these midges at Rothamsted is being explored. The danger of these midges being transported in infested heads from country to country has been demonstrated by breeding midges during April–May and October–December from a single small head of guinea corn received from Gambia during the previous December.

Aphid Problems

(C. G. Johnson, Bruce Johnson, Elsa Haine and L. R. Taylor)

It was shown last year that a principal factor determining fluctuations in numbers of aphids flying from hour to hour was the periodicity and rate of moulting of nymphs into alatae. Superimposed on this are flight behaviour changes. An analysis of both these factors, population and behaviour changes, is being made, both in the laboratory and in the field.

Dr. E. Haine is studying the factors which cause rhythmical changes in moulting and variation in length of the teneral period under laboratory conditions, with *Aphis fabae, Myzus persicae, Brevicoryne brassicae* and *Adelges* spp. She is also studying the take-off behaviour in wind. Contrary to accepted beliefs, it is found that aphids will, under certain conditions, take-off in wind well above their own flight-speed.

Mr. Bruce Johnson is working on the interaction of flight and reproduction and on the influence of flight on the behaviour of alatae *Aphis fabae.* Young, unflown alatae will not settle even on the most satisfactory host plants. After short flights the aphids undergo a behavioural change, and will settle and reproduce. The factors affecting the rate of birth of larvae by aphids which have flown is being studied. After the birth of a number of larvae the ability to fly is lost, and this is coincident with the autolysis of the flight muscles.

Dr. C. G. Johnson and Mr. L. R. Taylor continue the work on

dispersal of aphids at high altitudes and on the design and standardization of suction traps for this purpose. It has been necessary to construct extremely large and very powerful traps in order to sample adequately the low concentrations of aphids found at the higher altitudes.

These low concentrations are of great importance when studying the sequence of changes which occur throughout the day and night in the atmosphere and in the elucidation of factors responsible for the descent of aerial populations each day and their relation to weather.

The Natural Enemies of Aphids

(C. J. Banks)

Field studies on the natural enemies of aphids were continued during 1953, and additional information on the abundance of various species of predators throughout the year was obtained for comparison with results of earlier years.

Methods of rearing hoverfly larvae (Syrphidae) were investigated in the spring.

Some of the causes of the high mortality in the field of ladybird larvae (Coccinellidae) have been investigated. Causes of mortality in 1952 included cannibalism and predation by birds, but a shortage of food (aphid prey) was not considered a satisfactory explanation. It was considered, however, that larvae might not reach a food supply if they should search in an inefficient manner.

Experiments in the laboratory and in the field suggest that ladybird larvae, having found a supply of the prey, remain close to it; but while they are capable of making a thorough search of their surroundings, they appear to be inefficient in finding the prey, and this is advanced tentatively as being a contributory cause of the high mortality of the early-stage larvae.

The behaviour of larvae newly-emerged from the eggs has an important influence on their survival, for some larvae manage to procure food by attacking unhatched eggs. Such larvae probably have an advantage over the others if they can live longer and search a greater area for food. Experiments show that newly-hatched larvae fed on one egg of their own species can live, on the average, almost twice as long as unfed larvae, and the lifetime is extended even more by the provision of two or three eggs. This work continues.

The Ecology of the Heteroptera

(T. R. E. Southwood)

Attention has been concentrated on the species commonly occurring in hedgerows and the marginal land around fields; for it is these sites that provide a reservoir of both the predatory and phytophagous species.

Weekly samples of adults and nymphs from a strip of waste ground in the centre of Great Field have provided detailed information on the life histories of twenty species from the families Lygaeidae, Nabidae, Anthocoridae and Miridae. Samples were also taken from the margin of pastures. A large part of this year's work has

been the identification and description of the various instars of the nymphs of these species. Dissections of the last instar nymphs have disclosed parasitism by the larva of a Euphorine; this was frequently of a fairly high order, for example, 48 per cent in *Stenotus binotatus* Jak. on 6th July from Pastures.

A study of the structure and water requirements of the eggs is being made; and in connection with this is has been found that the structure of the egg is of considerable importance in the higher classification of the Heteroptera.

The Wheat Bulb Fly (*Leptohylemyia coarctata* Fall.)

(Barbara M. Stokes, D. B. Long and F. Raw)

Preliminary work was started on breeding a stock of wheat bulb flies for an investigation into their host plants. Healthy flies were maintained on several different diets, including one which consisted of fresh wild flowers and water only, and oviposition continued throughout the summer.

The wheat bulb fly has been known to occur, though not severely, on Broadbalk for some years, particularly affecting the wheat in the first year after fallow. In preparation for an investigation of the larval populations of this pest a survey has been made of the adult flies in the fields in the Broadbalk area. In late June and early July both male and female flies were abundant on Broadbalk. Few males were found outside Broadbalk, and none was found anywhere after the third week in July. During July and early August, with one exception, the female fly was found on all the crops examined. Apart from Broadbalk, it appeared to be most numerous on potatoes and sugar beet.

In the laboratory eggs were successfully obtained from adults bred from pupae and fed on milk, honey, pollen and water.

Following this year's wheat bulb fly attack on Broadbalk, soil samples were taken during December from those sections of selected plots which were fallowed in 1953 and those which were four years after fallow. It is hoped that these samples will yield data on the extent of egg-laying and the oviposition preferences of the flies.

Soil Arthropod Problems

Agriculture (F. Raw, R. M. Dobson and J. W. Stephenson)

The study of wireworm populations on the Ley and Arable Experiment in Highfield and Fosters field has been continued. The plots were sampled in September 1952 and September 1953. When the 1953 samples have been examined the results to date will be written up.

During April and May a marking and recapture experiment was carried out on the Ley and Arable Experiment in Highfield to obtain data on the abundance of *Agriotes* adults and their range of movement. Sixty traps were laid out, each consisting of a depression in the ground filled with chopped vegetation from the plot. The traps were examined every other day, the beetles marked individually, and liberated within 1 yd. of the trap in which they were caught. Over 1,000 beetles were caught in this way, and about 20 per cent were recaptured, some up to four times, but the results

have not yet been fully analysed. It appeared that there were real differences in population on different plots, and that where there was a dense cover of vegetation the beetles did not move far.

The Geescroft experiment on the chemical control of wireworms, carried out in collaboration with Insecticides Department, was continued to test the residual effect of treatments applied in the autumn 1951. Wheat was again used as a test crop, and as there had been no appreciable wireworm damage in 1952 the seeding rate was reduced to 2¼ bushels/acre to increase the effect of wireworm damage. Plant counts made in the spring showed little effect of wireworm feeding, but damage developed later, and was assessed by visual inspection. At harvest the yields of grain from the aldrin, chlordane, BHC and DDT plots were significantly greater than those from the BHC seed dressing and control plots. Wireworm counts made after harvest showed population differences which corresponded to the differences in crop yield.

1953 *results*

Treatment :	O	S	G	A	C	D
Yield of grain, cwt./acre ..	21·6	22·9	30·2	34·6	32·9	26·7
Wireworms per sq. ft. ..	11·9	10·0	3·9	1·0	2·9	3·3

O = untreated
S = BHC seed dressing at 2 oz. of the dressing/bushel
G = 3·5% BHC dust combine drilled with seed at 56 lb./acre
A = Aldrin combine drilled with seed at 200 lb./acre
C = Chlordane combine drilled with seed at 100 lb./acre
D = DDT combine drilled with seed at 150 lb./acre

A more detailed account of the yields obtained is given in the report of the Insecticides Department.

A study of the biology of the snake spotted millipede, *Blaniulus guttulatus*, by J. W. Stephenson has continued, but has been handicapped by the difficulty of obtaining material and of finding the apparently critical conditions for reproduction.

Experiments have shown that grassland species of millipedes prefer decomposing vegetation to fresh material, as do forest species. The palatability of a particular grass may be different for different species, and different grasses may differ considerably in palatability for the same millipede, e.g., *Alopecurus pratensis* is about twenty times more palatable to *Cylindroiulus londinensis* than is *Poa annua*.

Forestry (P. W. Murphy)

Dr. Murphy is at present engaged in analysing and collating the data obtained in an investigation of the meio- or meso-fauna of a heathland habitat in the Allerston Forest area, North-east Yorkshire. The main project has been a soil faunal survey of natural and afforested heathland. The fauna were extracted with a split-funnel extractor, a modified Berlese funnel. The sampling method consisted in taking blocks from heathland and forest sites, and cutting cores which were placed in the funnels, in an undisturbed condition. In a previous report reference has been made to experiments to test the efficiency of the extraction method. It is hoped to publish the results of this investigation in the near future.

A total of fifty-three species of Acarina have been recorded from natural heathland and forest plantings in the Allerston area. This total includes two new species, two new British records of genera (*Mycrotydeus* and *Eupalopsis*) and five new specific records. In the natural and undisturbed heathland the most common and abundant species are *Nanorchestes arboriger* Berl. (Endeostigmata), a small, active, saltatorial mite, *Carabodes minusculus* Berl., *Tectocepheus velatus* (Mich.) and *Chamobates* sp. (Oribatoidea). When compared with other habitats, the most striking feature is the small size of the heathland species. It is noticeable, too, that the Trombidiformes are frequently more numerous than in other situations.

The most important pedological attributes influencing the fauna in raw humus appear to be pore space and water content. Although the pore volume of the raw humus layer is usually in the region of 75 per cent of the total volume, much of it is either too small for the fauna or is occupied by water, and thus denied to these aerophilous creatures. The apparent density or volume weight of the raw humus milieu, that is, the ratio between the dry weight of a given volume of undisturbed soil and the weight of an equal volume of water, is a useful indication of the pore space available. Table 1

TABLE 1

Apparent densities, moisture contents and populations of Acarina and Collembola occurring in raw humus in natural, undisturbed heathland (litter excluded)

Depth (inches)	Numbers Acarina and Collembola		Apparent density (g./c.c.)	Moisture content, % of fresh volume	Moisture content, % of fresh weight
	Numbers	%			
0–$\frac{3}{8}$	460	82·1	0·19	45·4	70·9
$\frac{3}{8}$–$\frac{7}{8}$	65	11·6	0·28	61·0	68·8
$\frac{7}{8}$–$1\frac{3}{8}$	16	2·9	0·45	76·1	62·7
$1\frac{3}{8}$–$1\frac{11}{16}$	13	2·3	0·45	44·2	49·5
$1\frac{11}{16}$–$2\frac{3}{16}$	6	1·1	0·86	51·3	37·4

Note: These apparent densities are calculated on the basis of extraction dried weights, and are therefore somewhat higher than the values obtained from oven dry weights.

gives the apparent densities of the raw humus covering, and it will be seen that the ratio increases as one proceeds down the profile. In animal ecological studies moisture contents are usually expressed on a weight basis, but it is obvious that the apparent density gradient will affect these values and give a false impression of the water regime. Expression of water content on a volume basis overcomes this difficulty and indicates that the pore space in part of the raw humus layer is almost completely occupied by water. The larger populations occupying a greater volume of the drier raw humus resulting from " cultivation " and the presence of trees is additional evidence that water is an active competitor for living space.

From this study it is concluded that the meiofauna of the natural, undisturbed heathland is composed of large populations with a relatively small number of small species, which are confined to a narrow surface and subsurface zone of the raw humus. There

seems reasonable evidence for stating that water content, lack of suitable food material and perhaps lack of oxygen form effective barriers to any expansion of the faunistic structure or the appearance of larger species in this biome. These findings cast doubt on some of the pedological theories concerning the mechanism of development and maintenance of mor raw humus formations.

BEE DEPARTMENT

C. G. Butler

General

During 1953 the work of the department has proceeded along the lines which have been outlined in previous reports. Members of the department have given lectures to Scientific Societies, Beekeepers' Associations and other organizations, and have taken part in Summer Schools and similar short courses; they have also continued to serve on various committees, such as the Ministry's Bee Disease Advisory Committee.

A book entitled *The Behaviour and Social Life of Honeybees*, on which he has been working for some time, has been completed by C. R. Ribbands (145). This is essentially a reference book, and will, without doubt, be of considerable value to bee research workers.

A book on the organization and behaviour of honeybee communities, *The World of the Honeybee*, has been written by C. G. Butler for the New Naturalist Series (144).

During the year Margaret Ryle resigned in order to take up a new appointment in Cambridge. At the time of her resignation the programme of work on nectar secretion, on which she and others had been engaged for several years, was nearing completion, and it is hoped that it has now been completed by Elizabeth Carlisle. Many of the results of this work have already been published, and others (M. Ryle, 152, 153) are in the press.

Throughout the winter C. G. Butler was seconded to the Department of Agriculture of the Government of Ceylon, in connection with the Colombo Plan, to give advice upon the development of beekeeping and bee breeding in the Dominion. A Sessional Paper giving the results of these investigations and recommendations for the future development of beekeeping in the Island has been prepared (147). During the summer Dr. B. A Baptist was sent over by the Government of Ceylon in order that he might obtain experience in practical beekeeping and bee breeding.

Bee Behaviour

Effects of certain anaesthetics on behaviour

During the last few years claims have been made that if a colony of honeybees is moved a short distance whilst its members are anaesthetized with nitrous oxide they do not, on recovering from this anaesthetic, show any tendency to drift back to the original site of their hive, as they would do when anaesthetized with chloroform and other anaesthetics. It has also been been claimed that anaesthesia with nitrous oxide, unlike that induced with carbon dioxide, does not result in acceleration of the rate of change-over by individuals from household duties to foraging, nor inhibit the pollen-gathering activities of established foragers. This anaesthetic, if the claims mentioned could be substantiated, would undoubtedly be of considerable practical value, and efforts have, therefore, been made to check them.

The anaesthetic for which these claims have been made was prepared by its sponsors by adding ammonium nitrate crystals to the burning fuel in a beekeeper's " pipe " (used on the Continent for producing smoke with which to subdue bees during manipulation of their colonies). J. Simpson has demonstrated that the active agent in the fumes thus produced, which act very rapidly as an anaesthetic to bees, is certainly not nitrous oxide, but may be cyanides [which are, of course, harmful] and probably also some so far undetermined substance which appears to be a useful anaesthetic for bees. He has shown that pure nitrous oxide can produce anaesthesia only if it is used to dilute the oxygen in the atmosphere in which the bees are placed to about a tenth of its normal atmospheric tension at sea-level.

Simpson has found that no inhibition of drifting is obtained by anaesthesia with carbon dioxide, nitrous oxide or the fumes produced by adding ammonium nitrate to burning smoker fuel; furthermore, all three of these anaesthetics resulted in foraging bees ceasing to collect pollen, and also in acceleration of the histological changes in the pharyngeal glands of household bees which normally occur about the time when they first commence to forage.

C. R. Ribbands has also, independently, carried out experiments with nitrous oxide anaesthesia and found that the effect on drifting is negligible.

In practical, apiary, tests Simpson has shown that when whole colonies are anaesthetized with the fumes produced by adding ammonium nitrate to burning smoker fuel they occasionally fail to recover (probably on account of cyanide poisoning), but the results of his experiments suggest that this danger can be eliminated by using the minimum proportion of ammonium nitrate to fuel necessary to produce anaesthesia. Apart from its slightly toxic effect, this method, using the minimum quantity of ammonium nitrate necessary, appears to be the most efficient and simple one so far suggested for anaesthetizing whole colonies of bees *in situ*.

Foraging behaviour

C. R. Ribbands and Nancy Free (née Speirs) have continued their observations on the behaviour of individual worker honeybees which were visiting dishes of sugar syrup and have, as a result, suggested that, although the interplay of choice and memory enables a honeybee to exploit her environment very adequately, she is not an automaton who invariably chooses the best of those crops with which she has become acquainted. They have found that even if a bee has become aware of another dish which contains syrup of a higher concentration, she may continue to forage from another dish to which she is more accustomed. These observations confirm the existence of an aspect of bee behaviour which is implicit in earlier work but which has not hitherto been revealed by Ribbands' own observations, nor demonstrated in detail.

Swarming

J. Simpson has continued his investigations on the causes of swarming by studying the effects of combining overcrowding of the bees in the hive with either an excess, or a deficiency, of brood for

them to feed. From a preliminary examination, the results appear to confirm the previous year's conclusion that whilst overcrowding of the bees in the hive predisposes a colony to swarm, an excess of bees to brood has little, if any, such effect.

The organization of social life

C. G. Butler has shown that queen honeybees secrete on all parts of their bodies a substance (" queen substance ") which the household bees of their colonies urgently seek. This substance is obtained by young worker bees, who happen to be near to the queen at any given time, by licking her body. Many of the bees that have just obtained a supply directly from the queen move rapidly over the combs offering food which contains " queen substance " to other members of their colony. In this way " queen substance " becomes widely shared amongst the members of a colony. As long as worker bees obtain sufficient " queen substance " they remain inhibited from building emergency or supersedure queen cells, and from tolerating the presence of eggs or larvae in swarm queen cell cups (or artificial queen cell cups).

The " queen substance " of virgin queens appears to differ from that of mated, laying queens, but it is probable that all virgin queens produce one kind of substance and that all mated queens produce another kind. The results of experiments indicate that it is appreciation of the difference between the " queen substances " of virgin and mated, laying queens, rather than any difference in their behaviour, which enables worker honeybees to distinguish between them.

It seems probable that the readily demonstrable craving of workers for " queen substance " is one of the most important factors, if not the most important, in the maintenance of colony cohesion, not only in honeybees but also in the ants and termites. It is also very likely that it plays an important part in swarming; a temporary shortage of supply or, more probably, a breakdown in its distribution, leading to the toleration of eggs and larvae in queen cell cups.

It is hoped that the results of some parts of this investigation will be published shortly.

Clustering behaviour

J. B. Free and C. G. Butler have continued their analysis of the factors involved in the formation of a cluster of honeybees. They have been able to verify the fact, first demonstrated by Lecomte in 1950, that if one hundred or more worker honeybees are scattered individually in an arena in total darkness they will soon all come together to form a single cluster.

The bees appear to cluster together in this way in search of warmth and food and, if a queen is present, as usually occurs in nature, " queen substance ". (See Section on " The organization of social life ".)

Various factors combine to attract the " lost " bees together, such as the fact that the temperature of the incipient cluster is higher than that of its surroundings (if it is not no cluster is formed, and if it exceeds a certain level any cluster that has already formed tends to break up), the scent produced by the individuals of which the cluster

is formed, and the vibrations produced by the clustering bees. It has been demonstrated that each of these factors is, on its own, sufficient to induce clustering, even in total darkness. In the light, vision also plays its part in attracting stray individuals towards an incipient cluster.

It is hoped to publish these observations in detail before long.

Bumblebee behaviour

J. B. Free has continued his work on the behaviour of various species of bumblebees, with particular reference to the sizes of the foraging areas of individuals and their constancy to particular crops; the nature of the division of labour shown by the workers of a colony; and the physiology of caste production. He has shown that it is possible to induce queen production from the first batch of brood produced by an overwintered queen by providing her with ample food and attendant workers from other colonies.

General Research

Red clover pollination

E. Carlisle has continued the work on the effect of fertilizer treatments on nectar secretion by red clover which was begun by M. Ryle and herself. The results of last season's field experiments are now being analysed and prepared for publication. Two papers on this subject have already been written by M. Ryle (152, 153).

The yield of nectar appears to be the principal limiting factor in the attractiveness of red clover for honeybees. M. Ryle has demonstrated that marked variation occurs in the nectar yield between clones, and an attempt is therefore being made by C. G. Butler, J. Simpson and E. Tyndale-Biscoe to assess the possibility of selecting strains of established varieties of red clover with a much increased tendency to secrete nectar.

Experiments carried out in 1952, by the above workers together with J. B. Free, not only confirm the need of red clover for insect pollination but also appear to indicate that large variations in the percentage seed set can occur even with a population of honeybees larger than that required to pollinate all the florets. Before investigating the causes of such variations, it has been necessary to carry out further experiments to eliminate a possibility that they might have been due to constriction of the clover heads by the muslin bags which were placed over them. During 1953, therefore, a study of seed set variation has been made by a method which does not involve bagging the heads. The results appear to confirm the presence of variations in set even when excess honeybees are used to pollinate the flowers.

A comparison is also being made by J. Simpson between the proportion of florets in which seed is set on watered and unwatered plots of red clover. On account of the wetness of the summer of 1953, it is doubtful whether any differences will be demonstrable.

Queen introduction

As a result of his earlier work with J. B. Free on the way in which the worker bees of colonies respond to intruding workers from other colonies (see 1952 Report) and his own work on the existence of

" queen substance " and its importance in the maintenance of colony cohesion and organization (see Section on " The organization of social life "), C. G. Butler has suggested, as a working hypothesis, that the following points should be observed when introducing to colonies mated queens, of any age or strain: (*a*) the colony to be requeened should not be left queenless for more than a few minutes; the new queen should be introduced directly the old queen has been removed. The bees must not be allowed to suffer even temporarily from a deficiency of " queen substance " if it can be helped. Experiment has shown that the longer the interval between the removal of the old, mated queen and the introduction of a new, mated queen, the greater the chance of failure. (*b*) The new queen should be introduced alone, without attendants. The presence of attendants with strange body odours probably tends to alert the bees of the recipient colony, and this may lead to difficulties. (*c*) Ideally the queen should be released (by the bees) from her cage an hour or so after introduction, by which time any alertness caused by disturbance should have died down. (*d*) No food should be provided in the cage. The proper food for a mated queen is almost certainly brood-food, and the bees will provide this if the cage has a large mesh and is placed amongst bees of the right age. (*e*) The cage should be placed between combs containing the youngest larvae in the hive, as it is here that the nurse bees, who are producing brood-food, congregate. (*f*) The mesh of the wire-gauze of the cage must be large (3–4 mm.) so that the nurse bees can feed the queen and can lick her body, and thus obtain " queen substance ". (*g*) A colony should be left undisturbed for at least four days after a queen has been introduced in her cage, otherwise there is a slight risk of her being " balled ".

The cage suggested is made entirely of wire-gauze, and has one open end. The open end is covered with a single thickness of newspaper after the queen has been placed in it and just before it is put amongst the bees of the recipient colony. It has been found that the temporary reduction in the amount of " queen substance " in circulation before the queen is released from the introducing cage sometimes leads to the formation of a few emergency queen cells. However, experience indicates that these may safely be ignored, as the bees will destroy them after a day or two, when, presumably, the supply of " queen substance " has returned to normal again.

So far, 230 mated queens, including nearly 100 that had been in the mail or caged in the laboratory for anything up to five days, have been introduced by this method, with the loss of only one. With the aid of a number of beekeepers it is hoped to carry out further trials of this method during 1954. A preliminary report is being prepared for publication.

Bee Diseases

Nosema disease

L. Bailey has continued his work on Nosema disease. He has demonstrated that if the adult bees of an infected colony are transferred entirely on to clean comb-foundation early in the active season, the disease will be eliminated from this colony by the following spring.

It now seems quite definite that Nosema disease is carried over in a colony from one year to the next on old combs, and that infected bees do not transmit this disease to any significant extent at those times of the year when they can fly freely (150).

Successful attempts to fumigate combs and kill all the contained Nosema spores have been made at room temperature, both with the vapour of formaldehyde and with that of acetic acid. After exposure to the air for seven days combs that have been fumigated in this way did not appear to have any harmful effect upon the adult bees, or brood, of the colonies to which they were given.

The large-scale field experiments using the drug fumagillin against Nosema have been continued. It has been found that spread of the disease within overwintering clusters of bees, and the contamination of their combs with faecal matter containing spores of the organisms concerned, can be effectively prevented by feeding colonies with this drug in the autumn. Colonies treated in this way appeared to be healthy by the following spring, but subsequently, some mild relapses took place as brood rearing developed and the brood area expanded over comb which had not been completely cleaned of Nosema spores during the previous season.

It appears that the autumn is the optimum time of year for treatment of colonies with fumagillin, as the combs are in their cleanest condition at this time. The few bees which are still diseased are cured by the drug, and thus prevented from spreading the disease during the winter. Spring or summer treatment with fumagillin does not appear to be satisfactory, as the bees are cured only temporarily, and infection of the combs remains the same and the disease follows its normal course when treatment is discontinued (149).

Nosema infection reduces the proteolytic activity of the ventriculus of the adult bee, and also reduces the buffering power of the contents of this organ in the alkaline range. The inorganic phosphate content of the ventricular lumen increases significantly when infection develops, due presumably to the lysis of intracellular granules of calcium phosphate. The buffering power of the midgut of the honeybee in the alkaline range is not, therefore, due to inorganic phosphate, as has been suggested by earlier workers.

Other diseases

Work on Amoeba, Acarine and European Foul Brood diseases has been continued as opportunities occurred.

Bee Breeding

E. Carlisle has now completed a detailed biometric study of the honeybees of Europe and the Middle East. A few specimens of *Apis dorsata*, *A. florea* and *A. indica* have also been examined. The results of this work are being prepared for publication.

The production of queens of selected strains for trials has made considerable progress during the past year. Mated queens have been sent to a number of County Beekeeping Instructors and others who have kindly agreed to help with this work.

STATISTICS DEPARTMENT

F. YATES

There have been no major changes in our lines of work during the year, but the possibility of utilizing modern electronic methods of computation is under active consideration. M. J. R. Healy and D. H. Rees attended a course on programming methods for electronic machines held at the Mathematical Laboratory, Cambridge.

A new temporary building adjoining Rivers Lodge, sanctioned in 1952, is now almost complete, and will provide much-needed additional accommodation for staff and temporary workers. The Hollerith equipment will also be transferred to this building from its present cramped quarters.

F. Yates spent two months in India advising the Indian Council of Agricultural Research on the development of their Statistical Branch. This work was sponsored by the Food and Agriculture Organization of the United Nations, and was carried out in co-operation with Dr. D. J. Finney of Oxford, who spent a year in India (October 1952–August 1953). A report on this work is now almost complete.

D. A. Boyd acted as consultant on experimental design to the F.A.O. Working Party on Mediterranean Pasture and Fodder Development, and spent six weeks (October–November) in Rome, Greece and Cyprus. G. E. Hodnett was one of the instructors at the African Training Centre for Agricultural Statistics at Ibadan, Nigeria, which was conducted jointly by the Colonial Office and F.A.O. The course lasted for eight weeks (July–September), and was bi-lingual (English and French). Hodnett was responsible for giving the lectures on sampling methods in English and for advising on the application of these methods to problems of local importance. A duplicated set of lectures in summary form has been issued by F.A.O. (177).

F. Yates, M. J. R. Healy and F. B. Leech attended the 3rd International Biometric Conference held at Bellagio from 1st to 5th September, and F. Yates also attended the 9th International Genetics Congress (also at Bellagio) and the 28th Session of the International Statistical Institute from 7th to 12th September in Rome.

F. Yates was awarded the Weldon Memorial Prize by the University of Oxford for outstanding work in biometrical science.

M. H. Westmacott was granted leave of absence for six months to join the Everest Expedition.

Eight temporary workers were accommodated in the department during the year, two from Great Britain, five from the Colonies and one from Greece.

DESIGN AND ANALYSIS OF EXPERIMENTS

Work has continued on the problem, outlined in last year's report, of deciding what amount of experimentation is economically justified when questions of immediate practical importance have to be settled. A fairly full investigation has now been completed by

P. M. Grundy, M. J. R. Healy and D. H. Rees of the case in which a decision has to be reached whether to adopt some new treatment of the all-or-nothing type and there is only time to carry out one further batch of experiments after the initial experiment. This situation is somewhat similar to the double-sampling technique used in industrial quality control, but our approach has been different. Given the cost of a unit of experimentation and the gain resulting from a given difference between the old and the new treatments, it is possible to determine on the basis of the estimate provided by the preliminary experiment whether to carry out any further experimentation, and if so, how many experiments should be undertaken. A paper outlining the results of this work was given by Healy at the Biometric Conference. The solution of this problem has indicated that our previous ideas on the fully sequential problem in which units of experimentation are successively undertaken until a decision is reached require reconsideration. This problem is now being actively pursued.

A number of long-term Rothamsted and Woburn experiments are now reaching the stage where their termination or modification has to be considered. The three-course rotation on the effects of ploughing in straw was re-designed at the end of 1951, and the four- and six-course rotations are now under consideration. A plan for the re-design on modern lines of the rotation experiment laid down by Lawes and Gilbert on Agdell Field has been drawn up, but has not yet been put into operation, as certain irregularities on the field due to acidity have first to be corrected. Various other problems in the analysis of long-term experiments have been studied, and a paper has been prepared on the analysis of experiments containing different crop rotations (168).

There has been the usual volume of routine work on the design and analysis of field and laboratory experiments for Rothamsted and other research stations and for the National Agricultural Advisory Service.

The Unit of Animal Experimentation has been fully occupied. We have continued to assist various research stations and N.A.A.S. farms in the planning and analysis of their experiments. F. B. Leech's report to the Agricultural Research Council on the effects of thyroxine and iodinated casein on lactating cows has now been published (165).

Surveys and Operational Research

A survey of hill and livestock rearing farms has been begun in Wales and the Welsh border and in marginal and upland areas in Northern England, Yorkshire, Lancashire and the South-west. D. A. Boyd and B. M. Church are in charge of this work. This is a follow-up of the survey of marginal land which was undertaken in 1949–50. The object of the present survey is to find out how far improvements based on assistance given under the Hill Farming and Livestock Rearing Acts have affected the production, economy and working conditions. The surveyors are also estimating the scope for further improvements. Since most schemes are not yet completed, the present work will provide only a provisional estimate of the value of improvements, and it is planned to revisit the farmers

in four or five years' time to estimate the full effect. In addition to a random sample of improvement schemes, all those farms which have had schemes accepted under the Act are being visited, and further records are being taken covering areas of land which were already improved in 1949 to assess the long-term value of land improvement. The field work is now in progress, and it is anticipated that this survey will be completed by June 1954.

A survey of fertilizer practice has been carried out in eight districts. These districts were mostly new to survey or had not been surveyed for many years, and were chosen because of their particular interest to the advisory chemists concerned. A report is almost complete, except for one district, from which results have not yet been received.

The results of the 1952 survey of rabbit damage to winter wheat were examined, and a paper has been published (159). The survey gave the following estimates of losses in yield :

Province	Number of sites	Mean yield over all plots, cwt./acre	Estimated reduction in yield of grain, cwt./acre
Eastern	15	26·6	1·7 ± 1·4
East Midland	21	23·8	2·1 ± 1·3
South-eastern (Reading)	21	25·3	1·0 ± 1·5
South-eastern (Wye) ..	14	20·8	1·9 ± 1·8
West Midland	23	24·3	1·2 ± 1·0
South-western	25	21·0	1·6 ± 1·0
All provinces	119	23·6	1·6 ± 0·5
Kent, spring wheat, 1950	22	16·7	3·0 ± 0·7

A close correlation was found between the rabbit grazing observed in January and the final loss of yield, as is shown in the following table :

Extent of rabbit grazing in field	Percentage of sites	Mean yield		
		Fenced plots (cwt. per acre)	Unfenced plots (cwt. per acre)	Loss on unfenced plots (cwt. per acre)
None	30	25	25	0
Slight	36	25	24	1
Moderate ..	21	25	21	4
Severe	13	20	16	4

This provides satisfactory confirmation of the validity of the survey methods.

On the animal side F. B. Leech has continued his work in collaboration with F. W. Withers on the survey of diseases of dairy cattle carried out under the direction of the Veterinary Laboratory, Weybridge. This survey has now been extended to cover part of Devonshire besides being continued in Surrey, Berkshire and Wiltshire. The Ministry of Agriculture, Northern Ireland, are also about to investigate diseases and husbandry practice of cattle, sheep, pigs and poultry. We are assisting in the planning of this survey.

The survey of bloat carried out in Wales during 1952 has been

analysed and briefly reported on, and further work has been carried out in 1953. The results of this are now awaited.

We have co-operated with the Veterinary Investigation Officer at Leeds in the planning and survey of incidence of loss in pregnant ewes in Yorkshire. The results of this survey are now being analysed here.

We are also assisting various other departments in the planning of surveys and the analysis of the resulting data.

On the methodological side B. M. Church has carried out an investigation into the errors obtained in past surveys of fertilizer practice with a view to improving the efficiency of design and estimation processes. A paper has been prepared and is now being revised.

D. A. Boyd and W. J. Lessells have carried out a review of fertilizer experiments on grassland, and a paper on this subject was read to the British Grassland Society at their December meeting (158). They have also summarized all available experiments on the effect of seed rate on the yield of potatoes (157).

A paper by G. V. Dyke and P. R. D. Avis has been published on estimates of potato yields by sampling methods, based on the results of the survey of maincrop potatoes (161).

In the second edition of *Sampling Methods for Censuses and Surveys* (155) a method of sampling—lattice sampling—was described by which the effects of two or more cross classifications can be simultaneously eliminated. H. D. Patterson carried out an investigation into the appropriate methods of estimating the errors in the more complicated applications of this type of sampling (167).

F. Yates and P. M. Grundy carried out an investigation into selection without replacement from within strata with probability proportional to size (171).

Colonial Work

G. E. Hodnett has continued his work in advising and assisting workers in all parts of the Commonwealth in statistical problems. Five colonial workers have stayed in the department for periods of up to two months, and twenty others have paid brief visits. As already mentioned, Hodnett assisted in the African Training Centre for Agricultural Statistics at Ibadan. Reports on the analysis of sugar-cane experiments in British Guiana, Mauritius, Barbados and Antigua have been sent to the Colonial Office (178), and a combined paper is being prepared for publication. Hodnett also assisted D. H. Constable of the Rubber Research Institute of Ceylon in the preparation of a paper on a manuring experiment on rubber (160).

Other Work

The fourth edition of *Statistical Tables for Biological, Agricultural and Medical Research* appeared during the year (156).

F. Yates, D. J. Finney and V. G. Panse prepared a joint paper on the responses of food grains to fertilizers in India, summarizing the readily available experimental results (170). Yates gave an address to the Indian Society of Agricultural Statistics on the wider

aspects of statistics, in which he drew attention to the important contributions that can be made by statisticians to the planning of research and the utilization of the results in practice (169).

F. B. Leech assisted A. B. Paterson of the Veterinary Laboratory, Weybridge, in the analysis of an experiment on tuberculin reaction in the guinea-pig, and a joint paper is in the press (166).

M. J. R. Healy has contributed a chapter on biological assay to a new text-book on *Methods of Plant Analysis*, in which he discusses direct, parallel line, slope-ratio and probit assays, giving the appropriate statistical techniques and some suitable experimental designs (163). In this field of work he has devised a method of evaluating tests of fly-repellant sprays. In a common technique, sprayed and unsprayed mice are exposed to *Stomoxys* flies, and comparisons are made on the basis of the proportion of flies attacking the mice. The attack rate may vary widely from one occasion to another, and the problem lay in finding some stable basis for comparison (162). Jointly with G. V. Dyke, he has described a method for solving to three-figure accuracy large systems of normal equations that arise in survey analysis, using only a Hollerith sorter and tabulator (164).

As usual, a large number of papers have been referred to the department for refereeing; during 1953, forty-one papers were received. The work involved is very considerable, as the statistical analysis and presentation are often very unsatisfactory, and direct collaboration with the authors is frequently necessary in order to effect the required revision.

FIELD EXPERIMENTS SECTION

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments: E. M. Crowther (Chairman), H. V. Garner (Secretary), L. Broadbent, H. H. Mann, J. R. Moffatt, F. Raw, D. J. Watson and F. Yates.

The number of plots comprised in the field experiments at Rothamsted and Woburn in 1953 were:

	Grain	Roots	Hay	Grazing	Total
Classical experiments					
Rothamsted	131	72	47	—	250
Woburn	36	—	—	—	36
Long-period experiments					
Rothamsted	335	320	256	96	1,007
Woburn	133	314	55	12	514
Annual experiments					
Rothamsted	596	302	64	—	962
Woburn	—	64	—	—	64
Total	1,231	1,072	422	108	2,833

Some of these plots were put down on behalf of certain of the scientific departments for observation only, but 2,593 were carried through to the harvesting stage and weighed. In addition to the above, the farms accommodated some 600 microplots at Rothamsted and 100 at Woburn. Most of these were preliminary experiments carried out, observed and recorded by laboratory workers. In addition, the farm provided uniform areas of commercial crops, which were taken over, treated and intensively studied by the biological departments.

The weather conditions affecting agricultural operations are described in detail in the farm report; the following brief notes put on record the main features of the season 1953 to provide a general background for the year's experimental work.

Regarded from the point of view of the preparation of seedbeds and drilling of winter wheat and beans, the last two months of 1952 were distinctly unfavourable. November was 4° F. colder and also 1·2 inches wetter than average, and similar conditions persisted in December. The consequence was that on some fields drilling was late and seedbeds were rather poor. In these circumstances germination was slow, and very little growth occurred during the winter. Late drilled beans were badly damaged by birds; on the other hand, beans ploughed in earlier made good crops.

In the spring conditions improved. There were light showers, but practically no very heavy rain. Snow stood for ten days in mid-February, and then an unusually dry period set in, with practically a complete drought from the middle of February till the third week in March, with many ground frosts. The result was that the land worked down for spring seedbeds unusually well; even the deep-ploughed plots on the cultivation experiment gave mellow tilths. Sowing commenced at the end of February, and continued

without a check under ideal conditions. In spite of an excellent start, early growth was somewhat slow, owing to cold nights and dry soil. Growth responded to the milder amd moister conditions in April and more so in May, which was warm, bright and rather dry. Thereafter followed a "roots and grass" summer. June was cool, very dull and drizzly rather than excessively wet; July was very wet, with 3·8 inches, and also deficient in sunshine, towards the end of the month there were heavy falls, which lodged some of the cereal plots, in particular the barleys in the Highfield experiment. The first fortnight of August was dry, and corn harvest made good progress in spite of some lodged crops, but before the end a wet spell set in which delayed operations considerably. Potato harvest commenced in the last week of September, and a heavy crop was lifted without a check under ideal conditions, with the soil much drier than usual at this time of year. A feature of the autumn was the warm growing weather, which enabled the roots to make considerable progress in October, and gave a remarkable germination of weeds and shed corn on the stubbles.

The Classical Experiments

Owing to persistent wet weather, Broadbalk was not sown till 11th November on a seedbed that barely covered the seed, and it was mid-January before the rows were visible. Section I nearest the farm, carrying the second crop after fallow, was a good plant, and looked well throughout the season, but on the remaining sections the plant was much thinner than usual, and poppies, buttercup and bent grass were conspicuous. On Section II, first crop after fallow, the stand was particularly thin, so much so that the south side of the section from Plot 10 onwards when inspected in April could for all practical purposes be classed as a failure. In this badly affected area the only plot which appeared to be rather less damaged than the rest was Plot 15, which received all its nitrogen in the autumn. The cause of the damage was wheat bulb fly, a pest that had been noticed on several occasions on Broadbalk since fallowing started, and was very prevalent indeed in the Eastern Counties in 1953. In spite of the miserable appearance of the after fallow section in spring, the surviving plants tillered out and made a remarkable recovery in summer, and by harvest there was the promise of a fair crop.

Wild oats appeared to be diminishing slightly, thanks to the careful and systematic hand-pulling that has been carried out on Broadbalk for several seasons. On the other hand, leguminous weeds, chiefly trefoil and vetches, were particularly bad on Plot 5, minerals only, where the wheat was practically choked out by them. These weeds are beginning to spread to the neighbouring Plot 6, which receives only a small dressing of ammonium sulphate in addition to the mineral manures.

Hoosfield

The classical barley ground broke down in early spring to give an excellent seedbed, but in view of the very heavy infestation of wild oats in the previous year it was decided to leave the land unsown as long as possible in order that some wild oats might

germinate and be destroyed by cultivation. This was done, and the barley was not sown till 9th April. A good plant was obtained on all plots, but seedling growth was slow owing to low temperatures. Later wild oats appeared in quantity, and by the beginning of July they had topped the crop and spoiled the appearance of the field. The state of the plots was carefully considered. It was clear that the yields would have little value, so the most useful course would be to cut and cart the whole crop green before any oats had time to shed. This was done in mid-July. The spread of acidity in Hoosfield is becoming still more noticeable. In particular Plots 5A (complete fertilizer with sulphate of ammonia) and 3A (complete fertilizer without phosphate) show extensive central areas dominated by wild oats. The soils of these areas have been sampled in detail, and are under examination.

Barnfield

The season was particularly favourable for roots, and the field was sown on 10th April, on what, by Barnfield standards at any rate, would be called an excellent seedbed. The plant came well, and was kept growing by well-distributed summer rainfall. At lifting time the crop looked heavier than for many years, the completely manured plots carrying some very large roots indeed. The plant population, while fairly good, varied considerably from plot to plot, the thinnest plants being found on areas receiving ammonium sulphate, and probably now becoming acid in patches. The field has been thoroughly sampled in order to determine the pH distribution by individual plots. Judged by the appearance of the plants when in full growth, the superiority of nitrate of soda over the corresponding sulphate of ammonia plots was not striking, the nitrate plots being poorer and the ammonia plots better than usual, an effect probably related to the wet summer. In the matter of disease, the main pest, both in mangolds and sugar beet, was mangold fly, but the damage, though widespread, was scarcely enough to be serious.

Park Grass

Growth was late to start, owing to the dry cold weather in spring, when only Yorkshire Fog on the acid plots was at all conspicuous. Later the weather was much more favourable, and the yields promised to be above average. A feature of the season was the appearance of Yorkshire Fog in quantity on the limed ends of Plots 11_1 and 11_2; this had been gradually building up for several years, but was most noticeable this summer, rendering the contrast in species between the limed and unlimed ends of these plots very much less striking than usual.

Owing to showery weather, the plots were not cut till mid-July and baled under rather bad conditions. The second growth was lighter than usual.

Agdell

This field was drilled with barley in 1953 according to the standard rotation, but the plots were very exhausted, having received their last manuring in 1948. It was originally intended to harvest the barley in a large number of small plots to test the

uniformity of the various sections in preparation for a new long-period experiment based on the former treatments. As it turned out, the growth of barley was so poor that this scheme was abandoned and the usual six plots were harvested. There was a uniform plant over the whole area in the seeding stage, but by early May the side after clover was showing phosphate-deficiency symptoms, but these did not appear on the side following bare fallow, which was at this stage a better green colour and showed stronger growth. A month later the position of the two halves was reversed: the fallow side showed extreme nitrogen starvation, while the clover side was a much better colour, except in one corner of Plot 2, where extreme acidity had stunted the crop. Later the barley on the acid areas was largely suppressed by weeds and worse than the unmanured. A detailed soil examination of this field has been put in hand.

Long-Period Experiments

The long-period experiments were continued. The four-course rotation started in 1930 to test the residual values of organic manures and phosphatic fertilizers completed its twenty-year cycle in 1953, and is being worked up and summarized. A modified scheme of treatments for the continuation of this experiment is being worked out.

Deep-cultivation rotation

This experiment, testing the cumulative effects of deep and shallow ploughing, was continued for the tenth season. The deep-ploughed plots have now been moved to full depth on five occasions, but the light colour and lumpy tilth of these plots after deep ploughing is still noticeable. All the cereals looked better in spring on the shallow-ploughed land, but on wheat and barley the position was reversed by harvest-time, while on oats the superiority of shallow ploughing persisted. The effect of dung applied to the previous root crop was clearly seen in the vegetative growth of oats and barley. The deep-ploughed land lay very rough for sugar beet, but the clods crumbled down very well in spring and produced a finer and cleaner seedbed than the shallow-ploughed land. In the end there was an advantage of over 2 tons of roots per acre for deep ploughing. Dung was the most effective of the manures tested, although superphosphate showed a visible effect in the early stages of growth, which, however, was barely reflected in the final yield. The one-year seeds were good, and dung applied to sugar beet two years before raised the yield by 10 cwt. of hay per acre, and also clearly increased the proportion of clover in the mixture. The potatoes looked best on the shallow ploughing, and showed great improvement for dung and some benefit from phosphate. The haulm on plots receiving only nitrogen and superphosphate died back by the middle of August, particularly on the half-plots on which the phosphate was applied in the ridges.

Ley-arable experiments, Highfield and Fosters

There were two tests crops grown in 1953 to assess the effects of the different three-year leys: wheat for the first-year effects, and

potatoes for the residual effects after one wheat crop had been grown. The third test crop, barley, had not yet come into cycle, and merely showed the effect of extra nitrogen and of the residues of dung applied to the previous potato crop.

A good plant of wheat was obtained on both fields. On Highfield in early spring there was a visible difference between the tilth after cut grass and after arable cropping : the former was fibrous and fluffy, while the latter had been beaten down by winter rains. In mid-season, however, the crop looked much better on the old arable tilth than after cut grass, where the growth was noticeably patchy and irregular, at harvest the yield was 12·9 cwt. greater on the old arable land. Extra nitrogen had little visible effect on the crops at any stage, and the grain yield was actually decreased. Wheat after lucerne was judged in the field to be slightly better than wheat after arable crops, but at harvest the position was reversed, and as in the previous year the arable land yielded best. On Fosters lucerne gave about 4 cwt. grain more than the other treatments. Extra nitrogen to the wheat was more effective on Fosters than on Highfield, for it gave an increase of 1·9 cwt. per acre. Potatoes looked well on both fields and produced a heavy crop, differences between the various grass pre-treatments followed a somewhat similar pattern to the wheat, old arable giving the best yield on Highfield and lucerne on Fosters. Direct manurial effects were conspicuous, dung increased growth by 3·7 tons in Highfield and 2·8 tons in Fosters and lightened the leaf colour on both fields, high nitrogen gave rather small increases in yield, deepening the colour and if anything restricting the leaf growth. The barley was a heavy crop on both fields, and showed the usual effects from high nitrogen, but dung residues from the previous potatoes were also visibly beneficial. By 10th June the crop was badly lodged on Highfield, the severity depending closely on the manurial treatment, but a month later practically the whole area was flat and producing a strong growth of erect late tillers. The undersown seeds for next year's hay were killed out, and had to be resown in autumn. Conditions were similar, but much less severe, on Fosters. The main effects of the different cropping systems are given on p. 142.

The grazing plots had a favourable season. On Highfield grazing was started on 14th April and continued till 15th September. The teams of sheep were six for the permanent grasses, where the interval between successive grazing was fourteen to twenty-two days and four for the rotation grasses, where the interval was only eight to twelve days. At midsummer the stocking had to be reduced to three sheep per team, but the plots were continually grazed throughout the season. The three-year leys were particularly good on this field, the second- and third-year grasses having eleven grazing circuits and giving over 3 tons of dry matter per acre. On Fosters field the grasses were not quite so early nor the leys so productive as on Highfield, but the rate of stocking and the course of grazing was much the same. The season extended from 2nd May to 2nd October, and there was always some stock on the plots. The cut-grass plots grew well, and averaged 68 cwt. dry matter in five cuts on each field during the season, with a response to extra nitrogen of about 9 cwt. dry matter. Lucerne became very grassy in its third year on Highfield, but was much better on Fosters, where the third-year

Ley-arable experiments, Rothamsted, 1953

Effects of previous leys and arable cropping measured in two test crops

Mean yields : wheat cwt./acre, potatoes tons/acre

	After three years' cropping with :				
	Lucerne	Ley	Cut grass	Arable crops	Mean
	First test crop				
Highfield					
Wheat, grain	41·8	38·6	31·6	44·5	39·2
Effect of extra N ..	−2·2	−1·6	−4·9	−0·5	−2·3
Fosters					
Wheat, grain	41·3	37·2	37·4	36·3	38·0
Effect of extra N ..	4·8	−0·3	0·2	2·9	1·9
	Second test crop				
Highfield					
Potatoes	14·54	15·41	14·30	16·26	15·13
Effect of dung	4·54	2·82	5·14	2·41	3·72
Effect of extra N ..	1·05	0·97	−0·08	−0·60	0·34
Fosters					
Potatoes	12·05	11·58	10·16	11·46	11·31
Effect of dung	4·11	2·28	2·89	1·91	2·80
Effect of extra N ..	0·84	0·82	0·67	−0·23	0·53

plots gave no less than 113 cwt. dry matter during the season. In its second and third years it was the most productive herbage crop on both fields. The yields of the various preparatory crops in 1953 are given below :

Yield of herbage crops, Highfield and Fosters, 1953

Dry matter, cwt./acre

	Old grass		Reseeded grass		Three-year ley			One-year ley
	Hay	Grazed	Hay	Grazed	Grazed	Cut grass	Cut lucerne	hay
				Highfield				
Blocks :								
First year ..	—	36·8	—	46·6	44·3	75·9	58·9	59·5
Second year	—	42·5	—	56·4	63·8	73·1	103·1	—
Third year	37·6	36·4*	55·3	32·4*	62·4	68·2	84·7	—
				Fosters				
Blocks :								
First year ..	—	—	—	40·0	31·5	46·5	43·9	34·0
Second year	—	—	—	40·5	57·3	77·2	107·3	—
Third year	—	—	40·4	31·1*	51·4	67·0	113·2	—

* aftermath grazing.

Short-Period and Annual Experiments

These experiments fall into several sections : (1) Experiments on special fertilizer problems, where the Rothamsted trials are part of a series carried out at a number of outside centres. Fertilizer placement studies fall in this group. (2) Those in which the primary purpose is to provide data for the scientific departments, as for example the spread of virus or fungus diseases in the field in

relation to various agricultural factors. (3) Other Rothamsted experiments on general fertilizer or cultivation problems. Experiments in the first two groups are observed and reported by the scientific departments primarily concerned, and are listed below merely to indicate briefly their general scope.

Fertilizer placement experiments (G. W. Cooke, Chemistry Department)

(1) Barley—Highfield V, a comparison of British "nitrophosphate" and equivalent nutrients in standard forms, broadcast or combine drilled.
(2) Spring beans—Sawyers I, decalcic phosphate and superphosphate, broadcast or placed.
(3) Broad beans—Sawyers I, two levels of compound fertilizer, broadcast or placed.
(4) Lucerne—Highfield V, second year: residuals of fertilizer treatments applied in spring 1952: superphosphate, muriate of potash, broadcast or ploughed in, with and without a superphosphate application placed beneath the seed.

Experiments on eyespot (Cercosporella herpotrichoides) *in wheat* (M. D. Glynne and G. A. Salt, Plant Pathology Department)

(1) Rotation experiment—Little Knott, fourth year: wheat crop testing thirty-two different crop sequences on the incidence of eyespot.
(2) Wheat—Great Field I, second year: testing two varieties; two seed rates; two levels of nitrogenous manuring; four times of application of nitrogen; spraying in early spring with sulphuric acid.
(3) Wheat—Great Field I: testing four varieties; two seed rates; two levels of nitrogenous manuring; spraying with sulphuric acid.

Control of late blight on potatoes (J. M. Hirst, Plant Pathology Department)

Deacon's Field; effect of copper and sulphuric acid sprays.

Virus yellows experiment on sugar beet. (J. W. Blencowe, Plant Pathology Department)

Long Hoos VII; effect of three sowing and three singling dates.

Virus spread experiments (L. Broadbent, Plant Pathology Department)

(1) Potatoes—Long Hoos II, effect of repeated sprayings against aphids with five insecticides on spread of two viruses from infector plants.
(2) Broccoli—Stackyard Field, effect of dung and hoof at two rates on incidence of cauliflower mosaic virus.

Experiments on powdery midlew (F. T. Last, Plant Pathology Department)

(1) Wheat—Long Hoos III, time of application and quantity of nitrogenous fertilizer on winter- and spring-sown wheats.
(2) Barley—Little Knott I, two varieties; two times of spring sowing; effect of lime sulphur sprays.

Wireworm experiments (F. Raw, Entomology Department, and C. Potter, Insecticides Department)

Wheat—Geescroft Field, 2nd year: residual effect of five soil insecticides applied in autumn 1951 for the wheat of 1952.

Control of bean aphis (M. J. Way, Insecticides Department)

Beans—Long Hoos V; test of four spray treatments on winter and on spring sown beans.

Wild oats germination and growth studies (J. M. Thurston, Botany Department)

Cereal crops—Great Hoos; effect of autumn sown wheat, rye, barley and spring-sown barley on growth of wild oats.

Other Annual Experiments

Wheat, residual effect of dung

A heavy crop of wheat averaging 40·8 cwt./acre was grown on land that had carried in 1952 a test of farmyard manure on potatoes. The residual effect of dung was roughly proportional to the rate of dressing applied, and amounted to 1·6 cwt. of grain for each 5 tons of dung given to the previous crop. The manner of applying the dung to potatoes, whether ploughed in in winter or in spring or placed in the ridges, had no significant effect on its residual value.

Cereals, late nitrogen experiments

This is the fourth season in which dressings of "Nitro-Chalk" have been applied to cereals at the end of June when the crops were in ear. The experimental crops had all received fairly generous applications of nitrogenous fertilizer either in the seedbed or as spring top dressing, the object of the experiment being to ascertain whether late nitrogen would increase the protein content of a crop already adequately manured. The agricultural details may be summarized as follows:

		Basal manuring	Late N applied	Date of cutting	Interval, days	Rainfall application to cutting, inches
Wheat	Cappelle	29 Apr. 3½ cwt. S/A	29 June	19 Aug.	51	4·5
Barley	Herta	9 Mar. 2½ ,, ,,	25 June	13 Aug.	50	3·9
Oats	Marne	26 Feb. 2 ,, N/C	26 June	10 Sept.	76	5·6

There was ample moisture to carry the late top-dressings into the soil, and in this respect the season was similar to 1950, when the experiments were started and gave rather promising results. At harvest the wheat was all standing, the barley leaning but not badly

laid, but the oats were completely lodged, and were harvested by combine fitted with a sheet to catch the straw. The mean yields of grain and straw, the amount of crude protein and the percentage recovery of added nitrogen are given below :

Late nitrogenous top-dressings on cereals, Rothamsted, 1953

"Nitro-Chalk", cwt./acre	Wheat		Barley		Oats	
	Grain	Straw *	Grain	Straw *	Grain	Straw *
			Yield, cwt./acre			
0	31·8	44·6	38·6	39·8	42·1	42·4
1·5	32·2	43·3	40·3	39·3	41·5	43·7
3	31·8	43·3	42·0	40·8	40·9	42·0
			Increase in crude protein, cwt./acre			
1·5	0·12	—0·05	0·52	0·16	0·11	0·23
3	0·09	0·04	0·89	0·42	0·16	0·28
			Percentage uptake of added nitrogen			
1·5	8	—3	36	11	8	16
3	3	1	31	14	5	9

* Adjusted to 85 per cent dry matter.

All the cereals gave good yields without additional nitrogen in 1953, especially the barley and oats. Usually in these experiments the increase in yield of grain and straw following the late dressings has been negligible. This was so for wheat and oats in 1953, but the barley gave fairly large and highly significant increases in yield of grain but not of straw. There was the usual increase in nitrogen content of the barley grain and straw, and the final result was a gain of 0·68 cwt. of crude protein from the single top dressing of "Nitro-Chalk" and 1·31 cwt. for the double dressing, amounting to a recovery of about 45 per cent of the nitrogen added. This was the best result so far recorded in this series of experiments.

Oats with the extraordinary yield of 42 cwt. grain per acre without the late top dressing gave only 0·44 cwt. extra protein per acre and a recovery of 14 per cent of the added nitrogen for the highest level of manuring. In contrast to barley, the nitrogen tended to accumulate in the straw rather than the grain. In spite of the favourable season, late nitrogen gave negligible responses in wheat either in yield or nitrogen content. So far barley has been the most consistent crop in its utilization of late nitrogen.

Potatoes

A simple experiment testing farmyard manure, the three standard fertilizers and their interactions was begun in 1953, and will be continued yearly. There was a good crop showing large fertilizer effects. A dressing of 10 tons of dung gave an increase of 4·65 tons of potatoes in the absence of potash, but only 2·75 tons when muriate of potash was present. Superphosphate depressed the crop in the absence of dung and potash, but increased the yield in their presence, thus showing the positive PK interaction observed in many other experiments. Nitrogen increased the yield significantly, and was practically unaffected by any of the other manures. The residuals of the fertilizers applied to potatoes will be followed up in wheat in 1954.

Potatoes, method of planting and location of fertilizer

Continuing experiments on this question, a simplified scheme was adopted in 1953. Planting with a hand-dropping machine fitted with a fertilizer attachment was compared at two rates of compound fertilizer with the traditional method of broadcasting fertilizer over open ridges, hand planting in the furrows and splitting the ridges back over the seed.

Potatoes, method of planting and location of fertilizer, Rothamsted, 1953

Mean yield : tons/acre

		Compound fertilizer, 7 : 7 : 10½, cwt./acre ± 0·379		
Method of planting	Fertilizer applied	0	7½	15
By hand, in freshly open ridges	Broadcast, over ridges	6·78	9·44	11·30
By hand, in ridges exposed for eight days	Broadcast, over ridges	6·17	9·58	10·81
By machine, from flat	Broadcast, on flat	6·66 *	8·60	10·90
,, ,,	Placed near seed		8·69	11·01

* ± 0·268.

Responses to fertilizer were good at both levels. At the early stages of growth potatoes planted with placed fertilizer looked more vigorous than those put in by the standard method, but later the position was reversed. In the end the yield obtained from 15 cwt. of placed fertilizer was practically the same as that given by the standard procedure, a result in line with previous experiments, but at the 7½-cwt. level the advantage appeared to lie with the standard procedure. Moreover, in the present season placed fertilizer did not show its usual advantage over broadcast fertilizer, the two methods giving practically the same results at both levels. Exposing the ridges for eight days before planting, instead of planting and covering immediately, reduced the crop by only 0·3 tons per acre, a non-significant amount. During the period of exposure the weather was cool and overcast, and there was no severe drying out. The experiment also included a test of late top dressings of sulphate of ammonia and muriate of potash. These treatments were applied on 30th June before earthing-up to see whether they could maintain active growth in late summer and early autumn. No advantage was obtained this season from either fertilizer used in this way. Some burning occurred where the late top dressings had touched the leaves; this was appreciable where potash was used alone, but much worse where sulphate of ammonia was also present. The late nitrogen darkened the foliage slightly.

Experiments on soil conditioners

Four full-scale plot experiments, laid down in April 1952 at Rothamsted and Woburn, were cropped with carrots in 1953 to test the residual effects of a synthetic soil conditioner supplied as " Krilium CRD-189 ". The original treatments in 1952 had consisted of 0, 3 and 6 cwt./acre of the soil conditioner broadcast and 3 cwt./acre raked into the soil surface. The carrot crop of 1953 showed only small yield differences, except in an experiment of heavy soil in Warren Field, Woburn, where the yield was only 6·4 tons/acre on

plots with the surface applications in 1952 as compared with 8·2 tons on plots without soil conditioners.

In the spring of 1953 soil conditioners were available in mixtures with inert substances for more convenient application. Four small-scale experiments on carrots were laid out, two at Rothamsted and two at Woburn, in 4 × 4 Latin squares with dressings at the rate of of 10 cwt. active ingredient per acre in the following forms :

" Krilium 931 " (or " CRD-189 "), containing 25 per cent of the material used alone in the 1952 experiments;
" Merloam " (or Krilium 631 or CRD-186) containing 25 per cent of active material;
" Aerotil " (dry form), 40 per cent active material.

The conditioners were applied between 20th and 25th March, and incorporated by two rotary hoeings. Seedbed conditions were favourable in three experiments, but the heavy soil of Warren Field, Woburn, was rather hard.

Carrots, yields of total crop, tons/acre

Conditioner	None	" Krilium 931 "	" Merloam "	" Aerotil "	S.E.
Rothamsted					
Long Hoos ..	28·3	28·9	27·1	29·1	0·61
Stackyard ..	23·8	24·9	21·6	23·1	0·76
Woburn					
Stackyard ..	8·7	9·7	9·4	9·6	—
Warren ..	11·8	12·3	13·8	13·4	0·41
Mean of four experiments ..	18·1	19·0	18·0	18·9	—

The conditioners had no appreciable effect on yield at Rothamsted, and gave moderate increases at Woburn.

On several occasions there were clear effects of the conditioners on the physical state of the soil. At Rothamsted on 7th April the " Merloam " plots were dry and powdery on top after heavy rain on the previous day, while the untreated and " Krilium 931 " plots were quite moist, with the " Aerotil " plots intermediate. On 5th June the " Merloam " plots on Long Hoos field were dry on top with small hard clods, while the rest of the plots were moist, with clods that crumbled easily. After lifting the carrots in the Long Hoos experiment, the " Merloam " plots retained a more crumbly tilth than the other plots. The " Merloam " plots dried up more quickly and were less weedy than the other plots in the experiment in Warren field, Woburn; the " Krilium 931 " plots were the most weedy.

It is proposed to recrop the experiments started in 1953 to assess the extent of any residual effect from heavy dressings of soil conditioners.

THE FARMS

J. R. Moffatt

Rothamsted

The year 1952–53 was generally a very satisfactory one. Weather conditions, which always play a major part in the success or failure of a farming year, were very variable, and rather extreme. Despite this, the weather generally favoured farming operations this year, as crops were sown in good time, growth was continuous throughout the year and most of the crops were harvested satisfactorily. The major exception to this was the hay crop, much of which was spoilt by adverse conditions.

The very wet and hard weather in the autumn of 1952 gave the year a bad start, as less wheat was drilled than had been planned, and the winter ploughing was very considerably delayed. The germination of the winter wheat was severely retarded by the early onset of wintry weather, and hungry flocks of rooks and pigeons preyed on the seed. Two fields of wheat were so badly damaged that they had to be resown in spring.

A very welcome spell of fine weather occurred during the latter half of January 1953 and the early part of February, during which the ground dried out well. This enabled the ploughing to be finished and some fields to be ploughed a second time, while others were given a preliminary working for spring corn seedbeds.

The two weeks in the middle of February brought a return of wintry conditions, with frosts and falls of snow, but from the third week of February to the last week of March the weather was very dry. Fortunately the ground dried out fairly slowly, and so did not become harsh, and suitable seedbeds were obtained without any difficulty. Some 100 acres of spring corn were drilled and manured by mid-March. There was a large number of sharp night frosts, which, although not interfering with field work, must have retarded germination and growth of crops and grass.

The preparation of seedbeds for the root crops following immediately. Sugar beet was drilled under good conditions before the end of March, and potato planting was also well under way by the end of the month. Mangolds were sown early in April.

Growth of all crops was satisfactory during April and early May, but the milder weather in the latter part of May greatly accelerated growth. June was a month of cold, unsettled weather, with very little sunshine. Crop growth was retarded, but the warmer wet weather during July enabled good growth to be maintained. Unfortunately the wet weather, interspersed with thunderstorms, caused serious lodging of some of the corn. Weeds tended to flourish under these conditions, and became difficult to control.

The weather during the first half of August was generally fine and warm, and good progress was made with the corn harvest, which, however, started later than usual. Changeable conditions during the latter half of the month delayed these operations, but a fine spell during early September enabled the harvest to be completed early in that month. Unsettled conditions in the latter half

of the month delayed the start of potato lifting until early October, but then a spell of almost three weeks' dry weather enabled the crop to be lifted under almost ideal conditions. The experimental crops of winter corn were sown during this fine spell, and autumn ploughing made excellent progress. Heavy rain towards the end of the month delayed the drilling of non-experimental winter corn, but the mild and fairly dry weather in November enabled this work to be completed in good time.

The very mild weather persisted throughout November and December, and although the rainfall was small, it was spread over seventeen days in November and twenty days in December. The harvesting of the mangolds and sugar beet was done under good conditions and was completed early in December. The land continued to work well throughout these two months, and the work was well up to schedule. The mild conditions encouraged the growth of weed seedlings, and several fields were ploughed a second time before the end of the year.

Field Experiments

The number of experimental field plots at Rothamsted in 1953 showed a considerable increase over the previous year. Altogether there were about 3,000 plots, of which about 600 were microplots. A small number of plots did not have to be harvested, and some work was carried out by members of the scientific staff. However, as usual, the resources of the farm were strained, and long hours of work had to be put in by the farm staff at critical periods to enable the large programme to be carried through successfully. The experiments embraced most farm crops, and an account of them is given in the report of the Field Experiments Section.

Crops

Wheat

Some 85 acres of this crop were grown, of which about 27 acres were under experiments. Squareheads Master 13/4 was grown on the Classical experiments and on some long-term experiments, and Yeoman was grown on the more recent long-term experiments. On the non-experimental fields Cappelle replaced Nord Desprez as the main winter wheat, though a small area of the latter variety was grown, while Atle held pride of place as the spring wheat. No lodging occurred with the French wheats, and only patches of the Atle were laid. There was little evidence of damage by wheat bulb fly, except after the fallow section of Broadbalk. Although threshing is not yet completed, indications are that yields will be above average. The wild oats which were a serious menace on Broadbalk field a few years ago were further reduced in numbers by hand pulling, and the infestation is no longer serious.

Barley

Plumage Archer was grown only on experimental plots and blanket areas. This variety has been completely replaced on non-experimental areas by Herta and Proctor. The former has been grown very successfully for several years, and its strength of straw and high yielding capacity make it very suitable to our conditions.

However, its poor malting quality will probably result in its replacement by Proctor, which although of somewhat weaker straw and lower yielding capacity, has a much higher market value. Under the rather exceptional weather conditions of this year the Herta grown on some of the richer land was badly laid, although it stood well under more normal conditions. The Proctor yielded over 34 cwt./acre, and though it was leaning at harvest, no real lodging occurred.

Hoosfield, the Classical barley field, was so badly infested with wild oats that the whole area was cut and carted off before the oats ripened. This procedure will probably have to be adopted for some years in order to clean up the field, as the infestation is too severe to be dealt with by hand pulling.

Oats

The Dutch variety Marne was the only one grown in 1953. The crop looked very forward during the early summer, but unfortunately became badly lodged during July. Although losses from shedding were severe, the yield was high, and averaged about 33 cwt./acre.

Beans

The area under this crop was restricted to experimental plots. The season was remarkably suitable for beans, and both winter and spring strains yielded extremely well. There was no aphis attack, but weeds, especially mayweed, made rapid growth during the wet weather in July, when the crop was too high for inter-row cultivations.

Potatoes

The area under this crop was reduced from over 40 acres in 1952 to 27 acres this year, because of the difficulty of getting seasonal labour for lifting. The variety grown was Majestic, Stock seed being used on experimental plots and Class A seed on the non-experimental areas. All operations were mechanized, no hand labour at all being used, except for lifting.

The crop maintained good growth throughout the season. Late blight appeared towards the end of July, and two preventive sprayings were carried out, mostly at low volumes. The haulm was burnt off with acid, except for a small area where a mechanical haulm destructor was used. This proved unsatisfactory on our very stony ground. Lifting was done mainly by schoolchildren, and heavy yields were obtained. The crop was lifted under almost ideal conditions, and is stored under cover at the farmstead. Owing to the glutted market very few have been sold so far.

Sugar beet, fodder beet and mangolds

The area of each of these crops was restricted to experimental requirements, as the labour force available was unable to cope with the heavy demands at singling and lifting times. Sowing took place early under good conditions, and good growth was maintained throughout their life after an initial attack by flea beetles had been checked by spraying with DDT emulsion. The rapid growth of weeds presented a problem in the wet weather, but the crops were

kept reasonably clean. There were more bolters than usual in the sugar beet, and there was a fairly severe attack by the mangold fly on all three crops, which, however, grew away from the attack just as control measures were being considered. Harvesting was done under good conditions, and yields were well above average. The roots were of good size and shape.

Kale

A small area of Marrow-stem kale was grown for cutting and carting to cattle in yards, and Thousand-head was grown for folding by sheep. Although the crop was sown early under good conditions, at attack of flea beetles developed, but one spraying at low volume with an emulsion of DDT prevented any severe check or damage. Weeds were troublesome in the early stages, but were soon smothered by the rapidly growing crop. The crop is a very heavy one.

Grassland

The rather cold spring somewhat retarded the early growth of the grassland, but subsequent growth was very rapid, and the land remained productive until about the end of the year. No supplementary feeding was given to the livestock until sugar-beet tops were fed early in December.

The heavy rainfall and lack of sunshine during June and July made haymaking a very difficult and protracted operation. Cutting, making and carting were all delayed and interrupted by the weather, and the quality of the resulting hay was adversely affected. Some which was cut in late July appears to be the best quality. The hay was all baled, and is stored under Dutch barns at the farmstead.

Livestock

Cattle

There were a number of Aberdeen Angus and Hereford crossbred cattle in hand at the beginning of the year which could not be fattened in 1952 because of the shortage of grass. These were overwintered, some outside and some in yards, and were fattened, together with some younger Hereford-cross cattle, on the grass during the summer and autumn of 1953. Altogether fifty-nine beasts were sold, all without supplementary feeding.

In view of the apparent preference of butchers for light-boned cattle, it has been decided to fatten some crossbred Devon beasts, and to this end some forty young animals were purchased in the autumn. Twenty Hereford-cross cattle were also purchased, and both bunches will be fattened on the grass in 1954.

Sheep

The small and rather mixed flock of sheep were mated in the autumn of 1952 to Suffolk rams to lamb in late March and April. They produced 112 lambs at tailing time, giving a lambing percentage of 147. Some of the lambs were sold fat, but most of them have been retained for use on the grazing experiments at Rothamsted and Woburn in 1954. In the autumn of 1953 the whole breeding

flock was disposed of, and was replaced by eighty Scotch Half-bred gimmers. These were mated to Suffolk tups to lamb 1954, and the progeny will be kept for use on grazing experiments.

Machinery

New machinery purchases were mainly restricted to items replacing out-moded equipment, and to duplicating some equipment in great demand at peak periods of work. Such items include the replacement of a small wheeled tractor by a diesel-engined one fitted with an hydraulic lift, and the exchange of a vaporizing-oil tractor for a diesel-engined model. This gives a total of three of one make, for which there is a range of implements for direct mounting. A third combined seed and fertilizer drill and a drill suitable for drilling beans deeply were also purchased.

The mounted two-furrow reversible plough purchased in 1951 is being used to an increasing extent each year. Not only does it save time and fuel on the operation, but it leaves the land free from ridges and furrows, which are a severe handicap when laying out experimental plots. Once the fields have been ploughed by the reversible plough it seems a retrogade step ever to revert to the ridge-and-furrow method. Therefore a single-furrow reversible plough was purchased for the lighter tractors, and it is planned to standardize on the heavy tractors so that they can all take the mounted reversible ploughs.

The trials of the standard pusher-type combine harvester for harvesting experimental corn crops which were started in 1952 were continued in 1953. The results were again very encouraging, and a new 10-ft self-propelled machine fitted with a diesel engine has been ordered for the 1954 harvest.

The old road weighbridge used by horses and carts for weighing the produce of the Classical plots is being replaced by a new 20-ton dial machine suitable for tractors and trailers.

A full-time mechanic has been engaged to repair and maintain the equipment. Workshop facilities have been extended, and a gas welding plant has been purchased.

The wetter harvesting conditons of 1953 made it necessary to dry more grain than in 1952. Comparable figures for the fifty-hole platform drier for the two years are as follows :

	1952	1953
Quantity of grain dried	22 tons	60 tons
Average % moisture extracted	4·1	4·3
Units of electricity per cwt. dried	4·2	5·0
Units of electricity per 1% moisture extraction (per cwt.)	1·02	1·14

Buildings

No new building work has been undertaken, though some modifications to existing buildings have been made.

Plans are being considered for the bulk handling and storage of grain either in covered bins or in bins in existing buildings. The adaptation of part of the old stables to other uses is under consideration.

Estate Work

General estate duties, including hedging and fencing, were carried out during the year. Owing to the large amount of time taken in hedging, it is hoped to purchase a mechanical hedge trimmer in the near future. Several old post-and-wire hedges were renewed during the year. The woodlands were cleared of dead and dying trees, which have been sawn up for use on the farm.

Staff

Mr. S. Meyler has been appointed Deputy Farm Manager, and commenced his duties in April 1953.

Woburn

The work of the Woburn Farm was carried out under the direction and management of the staff of the Rothamsted Farm.

The year, although by no means an easy one, can be considered a satisfactory one, in that the result of several years' endeavours showed up in very satisfactory crops on the experiments and on the non-experimental parts of the farm. The attention paid to hedges, ditches and fences over recent years not only greatly improved the appearance of the farm, but resulted in a general improvement in the crops.

Of the 127 acres farmed, 60 acres were under cereal crops, 18 acres under potatoes and 33 acres under grassland of varying age. The remaining acreage was under various experimental crops, with a small fallow area.

The experimental field work was restricted to the Classical wheat and barley plots and the modern long-term experiments, except for some microplot experiments. In all there were 550 plots, of which 104 were micro-plots.

The year started off badly, as the adverse weather conditions in the late autumn of 1952 resulted in the wheat being sown rather late. Germination was delayed by the early onset of wintry conditions, and rooks and pheasants very seriously damaged the crop just as it was emerging. About 25 acres of wheat, fortunately all non-experimental, were almost completely destroyed, and had to be ploughed up. A small experimental area of spring cabbage on the Market Garden Experiment was so badly damaged by pigeons that it had to be scrapped, and two isolated areas of winter cabbage were also badly damaged.

Weather conditions improved considerably in the latter half of January, and the fine spell lasted well into February. During this period farmyard manure was applied to the potato crop, and several of the fields were ploughed a second time. After another short spell of bad weather a four-week spell of fine, dry weather enabled land work to continue without a check. Twenty-four acres of light land were given a dressing of 3 tons/acre of ground carbonate before sowing to Herta barley, and Atle spring wheat was sown on those areas where winter wheat was destroyed.

The preparation seedbeds for root crops followed, and good tilths were readily obtained. Sugar beet and early potatoes were

planted by mid-March, and main-crop potatoes were sown during late March and early April.

All crops made good growth during April and May, but the cold and unsettled weather during June slowed down growth. The warm, wet weather during July enabled all crops to put on a spurt of growth. During this month, with one exception, all corn crops were looking very promising. The disappointing one was Pioneer winter barley, and as its poor growth was erroneously ascribed to shortage of nitrogen, it was given 5 cwt/acre of nitrogenous fertilizer. Soil tests made after harvest showed that the poor crop was due to soil acidity. The root crops were cleaner and more forward than for many years.

The corn harvest started rather later than usual, and at first the weather was unkind. However, it improved by the middle of August, and the operation was completed by early September. All crops were cut by binder, and most were stacked under Dutch barns. No lodging took place on the non-experimental Herta barley or Atle wheat, but was severe on some experimental areas of Plumage Archer barley. Yields obtained so far are well above the average.

The main-crop potatoes, grown from seed from Northern Ireland, were lifted by casual labour obtained from Bedford on a piece-work basis. The yield was heavy, and the tubers were of excellent size and shape. Precautionary sprayings were given against late blight, and the haulm was burnt off by acid before lifting. Weather conditions were excellent for the early part of the lifting, but deteriorated towards the end. The crop is now being gradually disposed of. An experimental area of first earlies (Ulster Chieftain) was disposed of satisfactorily, but a small non-experimental area could not be sold owing to the glutted market and the presence of late blight on some of the tubers. These were eventually sold to the Ministry of Food as sub-standard, as were some of the main-crop variety, which were damaged by wireworms.

The small experimental areas of sugar beet were harvested under good conditions and yielded well. The roots were of excellent size and shape, but the sugar content was only moderate.

The small acreage of winter corn was drilled in excellent conditions during October and early November, and germination was good and rapid.

The mild dry weather during November and December enabled land work to continue without interruption. Dung was carted out for the 1954 potato crop, and nearly all ploughing was completed by the end of the year.

The crops on the Market Garden Experiment had a very favourable season after a bad start. The spring cabbage were destroyed by pigeons in the early winter of 1952, and were replaced by green peas; the red beet failed to germinate satisfactorily, and as the area rapidly became very weedy, the beet was replaced by white turnips. Both substitute crops yielded very well, and the following crops of leeks and spring cabbage are looking well. The leeks promise to give us a very heavy yield.

The wet weather in July gave the winter cabbages on the Green Manure Experiment a good start, and despite a moderate attack by clubroot disease, the plants have grown well, and heavy yields are now being obtained. The winter cabbage following early potatoes

on the Irrigation Experiment have made very disappointing growth, and are not hearting up at all well. None have been cut as yet.

The grassland was very productive throughout the season, after a rather late and slow start. It was all top-dressed with nitrogenous fertilizers during the season, and this, helped by the wet weather, prevented the usual shortage of grass in late July and August. Haymaking began late, and was a very protracted and tedious operation in the inclement weather, but yields were good and quality fair. The crop was mostly baled in the field with a pick-up baler. During the late summer and autumn some of the grass fields which had become rather acid were given ground carbonate of lime at about 3 tons/acre.

About 7 acres of very hilly land were chalked and seeded down under barley to a cocksfoot–meadow fescue–S.100 clover mixture, and a good take has been secured. A small area of very rough old pasture behind the farmstead was ploughed and reseeded to a lucerne–timothy mixture.

Twelve cattle were fattened on the grass during the summer, and graded satisfactorily. In view of the good stocks of hay and a plentiful supply of home-grown feeding-stuffs, more cattle are being wintered during 1953–54. Twenty-two crossbred Devon steers were purchased in the autumn, and because of the mild weather were still lying out at the end of the year.

The Large White pig herd was maintained at about ten breeding sows. Some of the older sows were replaced by gilts of our own breeding, but a new boar was purchased. Most of the pigs were retained to bacon weight, but any found making only small live-weight gains were sold for pork at an earlier stage. All pigs over about 100 lb. are weighed regularly. Of the eighty-one baconers sold since the start of the payment-by-grade scheme last April, 95 per cent were graded A.

Two infra-red heating units have been in use for very young pigs, and were found to be of great benefit in preventing overlying by the sows.

The feeding of antibiotics to some of the poorer pigs after weaning commenced in the autumn, but no experimental work is being done.

Very little expenditure was incurred on new implements, as the Woburn farm is now fairly well equipped. The light tractor running on vaporizing oil was exchanged for one with a diesel engine, so that both tractors are now fitted with this type of engine, which is showing great economy of fuel.

A small threshing machine fitted with a slow-speed peg drum was overhauled and converted to a high-speed beater-type drum, and will be used for threshing experimental plots. This will make the farm independent of Rothamsted for this work.

The difficult labour position eased considerably during the year, as two cottages were made available for farm workers. Also a pair of new cottages for farm workers have been erected by the London and Devon Estate Company, and are almost completed. When these are available, most of the regular workers will be satisfactorily housed, but casual labour will still be needed for work on the market-garden crops.

The covered yards have been completely re-roofed, and the badly

rusted purlins replaced. The drainage system in the yards has also been renewed.

The Woburn farm is now reasonably well equipped with machinery and buildings. The labour position has eased considerably, the fields are reasonably clean and fertile, and the hedges and ditches are in a satisfactory condition. Damage by game and vermin was considerably reduced in the last few months. The future at Woburn can now be faced with some confidence.

WOBURN EXPERIMENTAL STATION

H. H. Mann

SEASON

With a rainfall far (3·4 inches) below the average, but no drought during the growing season of all spring-sown crops, and with a cool summer up to the end of July, the agricultural year on the light sandy soil at Woburn in 1953 has been a good one, while the autumn has been almost consistently favourable for the harvesting of the excellent crops that have been grown. The only exception to this has been the rather poor growth of the grain crops sown in the autumn of 1952, which apparently suffered as a result of the dry weather in February and March 1953. The meteorological records from October 1952 to the end of 1953 are shown below.

Meteorological Records for 1952–53

Month	Rainfall: Total fall, inches	Rainfall: No. of rainy days	Bright sunshine, hours	Temperature, ° F.: Max.	Temperature, ° F.: Min.	Temperature, ° F.: 1 ft. in ground	Temperature, ° F.: Grass min.
1952							
October	2·96	18	98·7	53·5	41·0	46·8	36·9
November	3·24	16	65·4	43·7	32·7	39·9	30·0
December	2·06	19	68·3	41·8	30·0	35·8	27·7
1953							
January	1·16	13	32·8	41·7	32·5	36·9	29·5
February	1·62	11	68·5	44·3	32·2	37·8	29·2
March	0·62	7	126·2	50·9	31·5	41·0	26·7
April	2·34	13	158·3	53·4	37·2	46·0	32·0
May	1·64	11	204·3	63·2	45·4	55·6	39·9
June	1·92	15	110·3	64·1	48·9	58·9	46·1
July	2·97	20	190·4	68·0	51·9	61·9	48·0
August	3·11	11	223·2	70·0	52·2	62·5	47·4
September	1·41	11	169·9	65·1	48·2	57·8	42·7
October	2·13	13	68·4	55·8	42·3	61·1	37·4
November	1·31	10	55·2	30·9	42·0	46·1	37·3
December	0·58	13	32·2	47·9	39·9	45·0	36·4
Total or mean for 1953	20·81	150	1,439·7	56·3	42·0	50·9	37·7

Field Experiments

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that committee will report separately on them. There are, however, a few points in connection with them which may be recorded here.

Continuous barley

In the past two annual reports certain aspects of recent crops of barley which have been grown on this area have been discussed. The yield on all the plots has been declining for many years, even

with heavy nitrogenous manuring, and when the land became infested with wild oats it became necessary to fallow it for four years in order to get rid of this weed. Even then, though the wild oats had been eliminated, the area was so foul with spurrey that it was impossible to ripen the barley crop of 1951. As the crop of spring barley had become so poor, it was suggested that it 1952 half of each plot should be placed under winter barley, which grew so well in that year (see Report for 1952, p. 152) that it was supposed that the superior capacity of winter barley for smothering weeds and its greater root range might be the reason for its greater success. To test this, the areas which grew winter barley and spring barley in 1952 were reversed, with the result that the winter barley yielded no better than the spring barley. It is in fact clear that the better results with winter barley in 1952 were due neither to the reduced weed growth nor to the greater root range of the crop. This has led to an examination of the soil acidity, and it appears that in nearly all the plots, one half is more acid than the other, and the more acid half has in all cases given the poorer crop, whether of winter or spring barley.

It is, in fact, the difference in acidity which seems to be the primary cause of the apparent superiority of the winter barley reported last year. It is well known that barley is the most sensitive of the common cereals to soil acidity, and we have found in pot experiments that a critical acidity for this crop lies between a pH value of 4·8 and 5·0. The exact point where pathological symptoms appear seems to depend on the amount of organic matter and of soluble phosphate in the soil. The effect of acidity on barley, and the precise conditions under which it becomes injurious, have been studied in a long series of experiments at Woburn, an account of which is now being prepared for publication. In any case, there seems to be a tendency for land which is growing barley to become steadily more acid, whatever the nature of the manuring. Thus, in the continuous barley experiment at Woburn, where the original soil had a pH value of 6·1, the values at intervals of years have been found to be as follows :

	pH values			
Treatment to 1927	1888	1898	1927	1953
No manure	5·9	5·4	5·5	5·2
Nitrate of soda	6·0	5·9	5·9	5·5
Nitrate of soda and minerals ..	6·2	5·7	5·8	5·3
Farmyard manure..	6·1	—	5·8	5·3

Crop injury by industrial fumes

On 26th June, there appeared a blighted appearance on many of the crops at Woburn just after a serious and unusual fog. The damage was first noticed on barley, but on examination it was found on many plants, including wheat, oats and lucerne, and these showed brown patches on the leaves or other exposed parts of the plants. It soon appeared that this was not merely a feature of the crops on the experimental station, but also occurred on many other plants in the neighbourhood, including fruit-trees and especially young conifers in nurseries. This effect has been put down, locally, to effluvia from local brickworks retained near the ground owing to

the foggy conditions. Though this is as yet quite unproved, it has raised the question of the general results of factory emanations on vegetation in their neighbourhood. It is only in exceptional cases that damage such as occurred this year is sufficiently obvious, but it is more than possible that the yield of various crops may be affected long before any visible sign of damage would be noticed. We have not been able to follow up this question, but it is clearly important if occasional visible damage can occur, as in 1953, in an almost completely rural area.

Effect of irrigation on grass and clover

The irrigation experiment at Woburn started in 1951, under the general supervision of Dr. Penman, has afforded us the chance to estimate, on the grass ley plots in the experiment, the effect of watering on the proportion of grass and clover in the cut grass during the six or seven cuttings during the season. The results of 1953 are particularly interesting, as there was no period of drought, and the growth of the sward was continuous right through the season, even without the application of extra water. Under these conditions the effect of additional water still tended, as last year, to give more clover in the grass ley, though the difference was small. At the period when the growth of grass was at its height, the water caused the proportion of clover to go down very markedly, but at other times the proportion was always a little higher on the more heavily watered plots, except just at the end of the season. The actual figures for the seven cuttings on the plots receiving the most water are shown below :

Percentage of Clover in Cut Grass

	13th May	5th June	3rd July	4th Aug.	24th Aug.	16th Sept.	29th Oct.	Mean season
I. Low nitrogenous manuring								
No watering ..	42	40	25	29	27	29	19	30
Maximum watering	48	44	13	40	40	30	14	33
II. High nitrogenous manuring								
No watering ..	18	20	12	13	6	16	7	13
Maximum watering	28	27	11	17	25	17	7	19

In a year such as 1953 when the actual yield is not affected by watering, it is noteworthy that there was no appreciable difference between the sugar content of highly watered sugar beet and that which received no water. This agrees closely with what was found in the very different season of 1952.

New Crops

Maize

For the past fifteen years maize has been grown experimentally at Woburn with the object of obtaining grain types that could be economically grown in England. At first the attempt proved futile, for the only kinds of maize which would ripen in this country gave too small a yield per acre, and the more productive varieties

could not be relied upon to ripen. With the advent of hybrid corn, the situation changed, and some of the early hybrids developed in the northern United States of America have now for five or six years given economic yields of grain that can be relied upon to ripen, provided the site faces south and has a reasonably warm soil. Some of the American hybrids have now been acclimatized in Europe, particularly in Holland, and the seed of these has been further improved there.

The year 1953 has been very much a test year for these hybrids, for the early part of the season was so cold that little growth was made up to the middle of July, and at one time it appeared as if they would fail as commercial crops. When the weather became more normal in the latter part of July, the hybrids improved very much, and by the beginning of October it was possible to reap some of them with a satisfactory yield. For instance, a Dutch variety gave 31 cwt./acre of dry corn, harvested in November, while some of the others did almost equally well. It is clear that we have now types of maize which can ripen in this part of England even in an unfavourable year and give an economic yield. But the following points must be attended to if success is to be achieved. First, the seed must not be sown before the beginning of May; second, the land must be well manured with nitrogenous manures, which are best applied soon after the seed has germinated; and third, there must be some provision for drying the maize after it has been harvested, as otherwise it will go mouldy.

Fodder crops for semi-acid soils

(1) *Sweet lupins.* We have continued testing sweet lupins as a fodder crop in 1953. The previous two years were wet, and good yields had been obtained with Weiko, a variety developed in Germany. This was again tested, in the very different season of 1953, along with two other varieties, Neven and Pflug—the last being a white variety from South Africa. All were sown at the beginning of May, and all flourished, giving record yields of fodder on 7th September. The figures were as follows :

Variety	Yield of green fodder per acre, tons	Percentage dry matter	Dry matter per acre, tons	Percentage inedible
Weiko ..	27·8	12·4	3·45	25
Neven ..	24·1	12·6	3·04	42
Pflug ..	21·8	12·5	2·70	16

These yields are very high when it is considered that the growth had been made in four months, and on suitable soils sweet lupins should now take their place as a most valuable fodder crop. The dry matter of the fodder contained about 3 per cent of nitrogen, so that these lupins must be considered as a highly nitrogenous fodder material. The seed of sweet lupins has been used largely as a constituent of concentrated feeding-stuffs, but the yield of seed here has not yet been satisfactorily determined.

(2) *Serradella.* This is the fourth successive year in which we have obtained excellent yields of this very suitable fodder. Sown at the beginning of May, it gave on 24th August over 20 tons of

green fodder per acre containing 12·7 per cent dry matter, equal to 3·09 tons of hay. This follows yields of 2·14, 1·33 and 2·84 tons of hay equivalent per acre in the previous three years. It is only necessary to arrange for a supply of seed for this crop to become a very valuable addition to our fodder resources in the early autumn, on semi-acid light soils.

(3) *Birdsfoot trefoil.* This is supposed to be a fodder suitable for our class of land, and one which will flourish where conditions are too poor to give a normal growth of clover. It is a perennial, and gives a very large yield of fodder in the second year. When sown at the beginning of May, it shows little growth till after the end of July, but it can be cut for fodder at the end of September, giving a large yield. This year, the second year's crop was taken, and the following yields have been obtained with the narrow-leafed and the broad-leafed varieties :

Variety	Wt. green fodder per acre, tons	Percentage dry matter	Wt. hay equivalent per acre, tons
Narrow-leafed			
First year ..	12·5	—	2·8
Second year ..	20·5	21·5	5·19
Broad-leafed			
First year ..	?	?	?
Second year ..	16·5	21·4	4·16

The small area has now been left for a third year, to see whether it will continue to give yields of the same order.

Clover Sickness

There is little to add to what was said on this subject last year. The whole study has been completed so far as we are likely to go at present, and we are now able, with some certainty, to give a general explanation of the phenomenon. We have still not been able to isolate the toxic material in the soil which causes the clover failure; it is certainly not soluble in water, alcohol or neutral salts like potassium chloride solution. But it seems clear that this toxic material is sensitive to heat, that its influence can be reduced by the addition of certain forms of colloid matter, and that it gradually, though only very gradually, disappears if clover or a similar crop is not grown on the soil.

Laboratory Work

Work in the pot culture station and in the laboratory has again been restricted in 1953 by the demands of the irrigation experiments, and has hence been almost entirely concerned with what was necessary for the field experiments. Most of this work falls on Mr. Barnes and his staff, and they have been fully employed in these directions during the last year.

SOIL SURVEY OF ENGLAND AND WALES

D. W. King

Detailed surveying on the 6 inches to 1 mile scale has continued on sheets 70 (Leeds), 75 (Preston), 107 (Denbigh), 188 (Cambridge), 238 (Aylesbury) and 280 (Wells), and about 289 sq. miles have been mapped. Work on the Cambridge and Preston sheets is nearing completion.

Dr. A. Muir was seconded to the Government of Nyasaland for four months, and Dr. D. A. Osmond has been seconded to the Government of Cyprus for six months to initiate soil surveys in these territories. Mr. B. W. Avery spent a great part of the year in New Zealand studying soil-survey methods. Mr. E. Cutler, of the New Zealand Soil Survey, Mr. R. Ho, of the University of Malaya, Mr. P. K. Roy, of the Central Sugar Cane Research Station, Bihar, and Mr. C. G. Soteriades, of the Cyprus Agricultural Department, spent periods of one to several months with soil-survey parties.

Yorkshire

Sheet 70 (*Leeds*)

A further 32 sq. miles have been mapped in three separate regions.

The first was on the eastern side of the sheet between Tadcaster and Sherburn-in-Elmet, covering the junction of the Magnesian Limestone with the drifts of the Vale of York. The drift here consists on the whole of a sandy till overlying a calcareous clay, and the most widespread soil is the Ryther series. Depressions often have clay and silt deposits, or in some cases peat, which may be of considerable depth. Near Barkston a heavy soil, pinkish in the upper sub-soil, but mottled grey below, is probably derived from the Upper Permian Marl. The Limestone outcrop gives rise to soils of the Aberford series, in which have been included soils formed on the Strandline gravels, which consist largely of limestone fragments. The gravels round Stutton contain more sandstone fragments, and the soils have been mapped with the Rougemont series. The recent alluvium of the Wharfe is silty and of impeded drainage, and is liable to flood even in summer. The terrace between Newton Kyme and Tadcaster is sandy, and tends to be excessively drained.

The second area was on the north-eastern outskirts of Leeds, largely on Coal Measure Beds and the Rough Rock. This last material, a coarse, gritty sandstone, gives rise to the Scarcroft and Wigton series. Many red soils occur on the Coal Measures. These include sandy soils, mapped as the Kirby Overblow series, soils from shales, which give heavy red clays, and deep red micaceous loams formed on fine sandstone and siltstones. Drainage variants have been noted.

The third area mapped this season was in the north of the sheet between Thorp Arch and Healaugh, consisting of the easterly extension of the York and Escrick moraines. The soils and their

distribution resemble those mapped to the east. On the whole, they are medium and light textured and freely to imperfectly drained.

Lancashire

Sheet 75 (*Preston*)

Approximately 30 sq. miles have been mapped; mainly around Hutton, Leyland, Bamber Bridge and Walton-le-dale, together with a a few square miles north of Blackburn. In this latter area the soils are derived mainly from Carboniferous rocks and till derived from them, and belong to soil series described previously. In the other areas the parent materials are mainly drifts of Triassic or mixed origin, and here also the soils belong to series described in earlier reports.

The landscape between Leyland and Walton-le-dale is mainly gently undulating with sharply incised river and stream valleys. It appears that in most of the area a cap of till a few feet in depth is underlain by glacial sands. Soils formed on till, especially the Coppull series, are the most widespread, with Newport, Wem and Chorley series occurring mainly on the sides of the large valleys. West of Leyland, Farington and Penwortham, the topography is only very slightly undulating, and considerable areas were formerly covered by shallow peat, small patches of which still remain. Mostly however, the remains of the peat cover are to be seen only in the nearly black peaty loam and peaty clay loam surface soils, overlying mainly heavy textured till of Triassic material. The soils of the Salop series, and an improved phase of the Oaklands series, are the most widespread.

Several areas have been encountered, especially around Much Hoole, Longton and Hutton, in which old soil profiles formed on till and alluvium, sometimes peat covered, appear to have been overlain by a more recent alluvial wash.

Denbighshire

Sheets 107 (*Denbigh*) *and* 95 (*Rhyl*)

Approximately 105 sq. miles have been surveyed, completing the area west of a line through Rhyl, St. Asaph and Henllan. The soils mapped in the Silurian shale country have been described in earlier reports, but several new series have been established to the north and east.

The Carboniferous Limestone ridge between Llysfaen and St. George is largely covered with mixed drift. In addition to the Pentraeth, four series have been recognized: the Dinorben, a variant of the Penrhyn with a lighter texture due to admixture of colluvium from the limestone; the Castleton, a freely drained red loam developed on the basement beds of the Carboniferous; the Llysfaen, a light soil formed on Silurian shale drift with some admixture from the basement beds of the Carboniferous and the Morfydd, an imperfectly drained variant of the Llysfaen.

The Triassic till of the Vale of Clwyd has given rise to soils of the Cottam and Flint series, the latter occurring on steeper slopes. Small isolated patches of the Newport series have been mapped near

Rhuddlan. The soils on the large tract of marine alluvium between Abergele and Rhuddlan belong to the Wentlloog series and to a freely drained variant, the Rhuddlan series. Along the coast, blown sand overlies the alluvium and gives rise to the Pensarn series.

Deep, imperfectly drained silt loams, which have been provisionally included with the Conway series, occur on alluvium associated with the lower reaches of the Elwy and Clwyd. Near Llanerch the alluvium is lighter in texture, due to the local influence of Triassic material, and gives rise to deep freely drained fine sandy to silt loams distinguished as the Llanerch series.

Cambridgeshire

Sheet 188 (*Cambridge*)

A further 36 sq. miles have been surveyed this season. Mapping commenced on a ½-mile-wide strip along the eastern border of the sheet. One new series was established, the Worlington, a freely drained slightly calcareous soil derived from deep river gravels and sands overlying chalk.

To the south and west of Worlington the hummocky topography has given rise to a complex of soils. The Worlington, Moulton and Swaffham Prior series occur on the hummocks, while slightly mottled variants of these soils or peaty loams or peats are found in the depressions.

Work was also continued in the area of Girton, Histon, Milton and Horningsea and to the north around Stretham, Wilburton and Haddenham. In the former area the Peacock, Wicken, St. Lawrence, Newbarn, Wilbraham, Reach, Clayhythe, Milton, Landbeach and Lode series all occur in a small but intricate area east of the River Cam, together with disturbed soils resulting from coprolite digging. The Cam flood plain at this point is mainly occupied by soils of the Cam series, with some peats and peaty loams near Waterbeach. To the west, larger areas of the Milton, Landbeach, St. Lawrence, Newbarn, Peacock and Wicken series are found. The Milton and Landbeach are newly recognized series, occurring on the gravels and sands which form a low-lying terrace to the north of Cambridge. The Milton is a slightly calcareous freely drained soil with a sandy clay loam to clay loam profile with occasionally faint mottling below 2 feet. The Landbeach is a similar soil, but with coarse and often gravelly sand at about 2 feet. West of Histon the Wicken series is the dominant soil on the Gault.

The Lower Greensand outcrop near Oakington gives rise to a heavier textured soil than is found on the same formation around Cottenham. This new series, the Oakington, has a clay loam to sandy clay profile with some mottling below 30 inches. It is usually non-calcareous.

In the second area to the north the Wilburton ridge rises out of the Fenland. In the fens soils of the Bracks series alternate with shallow peat, whilst close to the ridge and on the lower slopes the Peacock, Newbarn and Oakington series are predominant. The crest consists mainly of the Cottenham and Oakington soils, with patches of the St. Lawrence and Stretham series.

Hertfordshire and Buckinghamshire

Sheet 238 (*Aylesbury*)

A further 30 sq. miles were mapped during the season. On the Chilterns the surveyed area was extended east of Great Gaddesden and in the country south and west of Tring. No new series were required, and the soil pattern conformed to that described in previous reports.

Work was also begun in the Vale of Aylesbury in the extreme west of the sheet to the north of Kimble and in a triangle with its vertices at Ivinghoe Aston, Mentmore and Wilstone. With the exception of the Lower Chalk outlier near Cheddington, both areas are largely flat or gently undulating, and are drained by small streams which arise from springs thrown out by the argillaceous basal beds of the Lower Chalk. Between this Chalk Marl and the Gault clay which underlies most of the Vale, a more sandy Upper Greensand facies is developed, especially in the west. Nearly the whole area is covered by drifts composed of locally derived material which has been resorted and redistributed by solifluxion or stream action. The soils so far encountered have a high base status, and apart from small areas on the Upper Greensand are slightly calcareous in the upper horizons and contain a zone of carbonate accumulation at about 3 feet.

The most extensive soil series on the Lower Chalk is the Wantage, which gives way on lower ground to the Burwell and Edlesborough series. This last is a calcareous slightly mottled clay loam formed on local alluvial or colluvial material. In a few places on the Upper Greensand platform fine-grained calcareous sandstones give rise to soils of the Harwell series. Elsewhere the soils are developed on more or less flinty drift, and two new series have been recognized: the Marsworth, a light brown slightly calcareous slightly mottled clay loam over a glauconitic fine sandy clay, and the Cheddington, a brown slightly mottled clay loam over very pale olive brown slightly calcareous fine sandy clay.

The main area of the Gault is covered by soils of the Peacock and Wicken series. On the extensive areas of gravel to the north of Wilstone, a new series, the Gubblecote, a freely drained calcareous soil, usually a sandy clay loam overlying the coarse flinty gravel, has been established.

Somerset

Sheet 280 (*Wells*)

A further 56 sq. miles have been mapped in the southern portion of the sheet.

Organic soils are largely confined to Tealham Moor and Aller Moor, and have been mapped with the Sedgemoor series and the Turbury Moor complex. In Mark Moor and in the area to the north of Mark a uniform stretch of soils belong to the Wentlloog series, whilst to the west a poorly drained variant has been established as a new series, the Allerton. Stoke and Draycott moors were largely mapped as the Godney series, and to the south-west lighter estuarine deposits give rise to a new series, the Latcham, an imperfectly drained silt loam over pale mottled silt or fine sand.

Other established series identified and mapped on the borders of the moors are the Butleigh and Fladbury south of the Wedmore Ridge, and the Tewkesbury, Compton and Midleney around the Axe level.

Most of the soils of the Wedmore ridge itself have been mapped as previously established series; the Evesham, Charlton Bank, Somerton and Haselor. Two new series have been recognized formed on sandy and sandy clay facies of the Rhaetic: the Sand Hall a freely drained and light-textured soil overlying sandstone, and the Wedmore, a strongly mottled loam overlying a mottled grey sandy clay passing abruptly to a stiff brown clay in which limestone beds occur. The rather steep north-facing slopes of the ridge show a transition from the Evesham series at the top through the Hurcot series on the slopes to the Worcester series at the bottom.

The soils formed on the level top of Mendip are subjected to a rainfall of 40–45 inches, tend to form a mor humus and to have a thin iron pan under conditions of imperfect drainage. Large areas of the Carboniferous limestone are covered with the Nordrach series, a silt loam passing down into a silty clay loam changing sharply to a reddish brown clay. Two new series have been recognized on Devonian material; the Masbury, a freely drained light loam over sandstone, and the Thrupe, a gleyed soil on colluvium.

The south-facing Mendip slopes exhibit the established Langford, Worcester, Wrington and Lulsgate series in order of increasing altitude. The soils of the Lulsgate series are very shallow, with frequent outcrops of limestone.

Other Work

Reconnaissance surveys were made of sheet 84 (Wigan) and of the parishes of North and South Kelsey in Lincolnshire. Frodsham Marsh in Cheshire was mapped on the 6 inches to the mile scale for the Agricultural Land Commission. Detailed soil maps were made of the University of Leeds Farm at Wise Warren and of Brogdale Farm, Faversham, Kent, the latter in connection with the transference of the Wisley Fruit Trials. Advice on soil problems has been given on opencast coal sites, marginal-land improvement schemes and other agricultural properties.

BEES AS POLLINATORS OF FRUIT AND AND SEED CROPS

By

C. G. Butler and J. Simpson

I. Introduction

It has been shown that a number of important agricultural crops require the services of insects as pollinators. Whilst this does not apply to the major crops required for human consumption, such as cereals and potatoes, it is particularly important in the case of the legumes, which play such an essential part in agricultural economy. Many other crops require insect pollination in order to produce fruit or seed, of which such horticultural crops as brassicae and orchard fruits are good examples.

It should also be mentioned that many grasses and forest trees, which rely on wind pollination, are frequently visited by large numbers of pollen-gathering bees (Synge, 1947).

Although adequate data are not yet available, it is probable that in many parts of Britain today, as a result of intensive cultivation, the number of wild pollinating insects is insufficient to ensure full production. However, the distribution of honeybee colonies is by no means ideal for this purpose, since the great majority are kept in the immediate neighbourhood of large cities and not in those areas where insect-pollinated crops are extensively grown. This state of affairs is harmful both to the farmer and to the beekeeper, whose honey yield suffers as a result of excessive competition for limited supplies of bee forage. Its rectification is, however, clearly a matter of organization rather than of research, and the research worker is more concerned with those cases where, despite the presence of bees, pollination still remains inadequate.

II. Insufficient Pollination

Many insects, including bees, visit the nectaries of flowering plants in search of food. It has been shown by Wykes (1952*c*) that honeybees prefer solutions containing sucrose, glucose and fructose to solutions of the same total concentration of any single one of these sugars. The fact that most nectars contain these three sugars in major proportions (Wykes, 1952*a*; 1953*a*) may, therefore, indicate an aspect of the mutual adaptation between plant and bee. Wykes (1953*b*) has also found that the removal of nectar from the nectaries of some plants stimulates further secretion—an interesting example of economy on the part of the plant.

In most cases the nectaries are situated within the flowers themselves and, when approaching them, the insects usually effect the pollination of the flowers concerned. Floral nectaries are probably more attractive than extra-floral ones, and also the more readily found on account of the colours and scents of the flowers. It has been shown by Oettingen-Spielberg (1949) that worker honeybees searching for new sources of food are particularly attracted to small, coloured objects. This has been confirmed by Butler (1951), who

has also shown that bees will alight on such objects much more readily if suitable scents are also present. Furthermore, he has shown that bees that have been visiting a crop of scented flowers for some time will hesitate to enter them if the perfumes of the individual flowers are experimentally masked with another perfume, even with one which is normally attractive to bees. This probably explains the observation of Butler, Finney and Schiele (1943) that many bees are deterred, at least temporarily, from continuing to visit flowers when they are sprayed with insecticidal and fungicidal mixtures containing scented materials which are not, in themselves, strongly repellent to bees.

Bees are especially important as pollinating insects because, both as larvae and as adults, they are entirely dependent upon nectar and pollen for their food, and numerous visits have to be made to flowers to collect them. The branched hairs on their bodies, which enable them to collect pollen, also increase their pollinating efficiency. The honeybee is especially valuable because its colonies contain thousands of individuals which can readily be moved to those places where they are required.

Failure of bees to work on crops is often explicable by lack of nectar or by the presence of nectar which is too dilute to attract them. Some plants consistently produce nectar which, both in quantity and quality, is attractive to bees, whilst others cannot be relied upon to do so. Such variations in nectar secretion can usually be attributed to weather conditions, even to those of the previous year, through their effect on carbohydrate accumulation (Wykes, 1952*b*), but may also be affected by the availability of soil nutrients (Beutler, 1953). Ryle (1954*a*, 1954*b*) has investigated the effect of fertilizer treatment on nectar secretion in mustard, buckwheat, apple and red clover. She showed that with apple-trees the mean quantity of sugar produced per flower was significantly increased by extra potash. In sand-culture experiments with red clover, mustard and buckwheat, in which the levels of nitrate, phosphate and potash were varied, any treatment which checked growth at flowering, apart from a shortage of potash, increased the yield of nectar. However, with the clonal material used in the red-clover experiments, it was found that the differences caused by the fertilizers were small in comparison with those between clones. This suggests that it may be possible to select strains of red clover which, whilst retaining their present good vegetative qualities, will also have improved nectar-secreting properties.

It is also possible for flowers to contain nectar which is not available to all pollinating insects. Thus inadequate pollination of red clover by honeybees can be due to the long corolla-tubes of the flowers of this plant, which make it difficult, if not impossible, for the bees to reach the nectar unless it is very plentiful. The longer-tongued species of bumblebees, such as *Bombus agrorum* and *B. ruderatus*, are better able to pollinate this plant, but the short-tongued species, such as *B. terrestris* and *B. lucorum*, are often actually harmful, since, by biting holes at the bases of the corolla-tubes, they obtain the nectar without making contact with the stamens and stigma, and enable honeybees to do likewise. These facts have recently been verified by Free (1952). Ribbands (1951) has shown that in order to obtain maximum pollinating efficiency

colonies of honeybees should be placed as close as possible to the crop, since the amount of foraging in bad weather is considerably reduced when the bees have to fly even short distances.

Numerous cases have been recorded of crops which would otherwise be reasonably attractive to bees being neglected in favour of still more attractive crops, which have sometimes actually been weeds. For example, Vansell (1942) has described a case of competition, a multiple case, between the flowers of apple, peach, nectarine, plum, sour cherry, winter Nelis pear and Bartlett pear, in which the two varieties of pear were almost completely neglected by the bees present in favour of the apple and other flowers. Butler (1945*a*) has described similar cases of competition between pear and hawthorn, in which the pear blossom was neglected in favour of the hawthorn, and also between greengage and dandelion, in which the dandelions received the bulk of the bee visits. Hammer (1949) showed that red clover, even when it was yielding nectar well, was liable to be deserted in favour of mustard, lucerne or carrot. He found that this difficulty could be overcome by providing more bees than the competing crops could carry.

Bees foraging for nectar may in some instances be ineffective as pollinators if the floral structure permits them to reach the nectaries without touching the stamens and stigma. Thus some varieties of apples have long, erect stamens beneath which bees can crawl to reach the nectaries. In the case of flax many bees learn to approach the nectaries by thrusting their tongues between the petals from the back of the flower (Gubin, 1945), in which behaviour they are possibly encouraged by the fact that flax petals are extremely loosely attached and perhaps do not provide an adequate support for a bee (Simpson, 1949). In the same sort of way nectar-gathering honeybees rarely accomplish the tripping of lucerne flowers, which is necessary for their pollination, having learned to obtain the nectar without thrusting their heads into the corolla-tubes (Tysdal, 1940). Honeybees often take a little time to learn such irregular methods of obtaining nectar (Butler, 1949), and Dadant (1951) has suggested changing the colonies on the crop regularly to reduce the effects of such learning.

Extra-floral nectaries on plants also allow insects to obtain nectar without effecting pollination. It is surprising, therefore, that in some plants, such as the field bean and cotton, such nectaries are active at the time of flowering.

Where it is sufficiently abundant, pollen of itself may attract pollinating insects. This occurs with a few nectarless plants such as poppies. Since pollen-collecting bees almost invariably pollinate the flowers which they visit, most pollinating difficulties could be overcome by increasing the number of bees gathering pollen from the crop. This can be done by increasing the total bee population in the district. About one colony of bees per acre is usually sufficient to ensure the pollination of crops where nectar-gatherers are the effective agents (Hutson, 1926), but advantages have been shown in increasing this number to three to four per acre in the case of red clover, from which the bees often obtain insufficient nectar (Hammer, 1950), and to five per acre with lucerne, where nectar-gatherers do not pollinate the flowers (Dadant, 1951).

Many more individuals are usually necessary to gather the

nectar required by a colony of honeybees than are required to collect its pollen. It follows, therefore, that if the population of honeybees in any given area is increased, until the number of pollen-gathering bees is sufficient to pollinate a given crop, the colonies used are unlikely to give a satisfactory return of honey and may even require to be fed. The economics of this system of ensuring pollination in any particular instance should, therefore, be carefully examined. The females of many solitary bees, for example *Megachile* sp., are mainly concerned with pollen collection when foraging, and are, therefore, probably more useful as pollinators of crops such as lucerne (Franklin, 1951), from which honeybees can obtain nectar without effecting pollination. Attempts have already been made in America to propagate *Nomia melanderi* for this purpose (Menke, 1952); otherwise this possible method of solving the problem appears to have received little attention.

The possibility of varying the proportion of pollen to nectar loads collected by honeybee colonies has been considered. There is some evidence that this can be done by creating a pollen shortage in the hive by using a pollen trap to remove pollen from the legs of returning foragers (Hirschfelder, 1951; Lindauer, 1952). Most traps, however, remove only about 20 per cent of the loads of pollen brought in by bees, and although a trap which removes as much as 75 per cent has been produced at Rothamsted, the obstruction which it causes reduces the foraging level of the colony excessively. Unless this difficulty can be overcome, it seems improbable that pollen trapping will prove to be useful in this respect. Pollen collection may also be increased by adding to the amount of brood in the colony, but this, too, involves considerable beekeeping difficulties.

III. Cross-Pollination

Many plants of considerable economic importance are wholly or partially self-sterile, or possess mechanisms which hinder self-pollination. It is important, therefore, that pollinating insects should carry pollen from plant to plant.

Individual honeybees do not forage over the whole of the area within flight range of their hive, but tend to return continually to a small part of this area (Müller, 1882). This type of behaviour is also shown by other insects (Minderhoud, 1951), and may well be a characteristic of foraging animals in general. Individual bees also frequently restrict their activities, at least for a time, to the flowers of one of several available species of plants (Aristotle).

It is obviously desirable that the foraging areas of individual honeybees should be large where the transference of pollen between trees, often between widely separated trees (as in orchards interplanted with compatible varieties), is necessary; and that they should be small where transfer of pollen between adjacent plots, as when growing seed of compatible varieties of brassicae, must be avoided.

Butler (1943) described honeybees restricting their foraging on a crop to areas of 5 yards or less in diameter, and the existence of foraging areas of similar size was deduced by Crane and Mather (1943) from a study of the distances necessary for isolation between

crops of different varieties of radish. It was pointed out by Butler (1943) that bees foraging in such small areas cannot be responsible for cross-pollination in orchards, and, since the necessary transfer of pollen between trees does occur, he postulated (1954*b*) the existence of an additional " wandering " population of bees. He considered that these were probably mainly young bees which had not yet found satisfactory foraging areas. It was known, however, that bees tend to extend their foraging areas and to wander when the crop on which they have been foraging begins to fail. Thus in an experimental field, which extended over a considerable area, in which artificial flowers (dishes of syrup) were spaced 20 yards apart from one another, Butler, Jeffree and Kalmus (1943) found that honeybees which were accustomed to collect food from particular dishes moved elsewhere when the supply of syrup in these dishes failed, but, nevertheless, returned from time to time to these dishes and examined them. If the supply of syrup was subsequently replenished and maintained, the bees would often be found to have enlarged their original foraging areas to include several dishes, some of which they visited only occasionally. Similarly, Ribbands (1949) found that honeybees that were gathering pollen from Shirley Poppies spread their activities over a greater number of flower-heads as the supply of pollen became exhausted. From this and other observations with different crops he came to the conclusion that the size of a honeybee's foraging area is liable to continuous change, and is dependent at any given moment on the extent to which she is satisfied with the return for her foraging activity. Since von Frisch (1934) has shown that such satisfaction is related to the previous foraging experience of a bee, it is probable that as different bees have had different experiences they are liable to be variously satisfied, and Ribbands (1949) has concluded that one is likely to find a wide range of sizes of foraging areas amongst any population of honeybees working on any crop at any given time. Thus both Butler and Ribbands agree that the sizes of the foraging areas of individual bees vary from time to time, but explain this phenomenon in different ways.

Butler (1945) supposed that the proportion of " wandering " bees could be raised by increasing the density of bees on the crop, but Ribbands (1953) has concluded that the effect of competition on the sizes of foraging areas is unpredictable from the available evidence. This problem, which clearly has an important bearing on orchard pollination, still remains to be solved experimentally.

IV. The Directing of Honeybees to Crops

Von Frisch's (1925) discovery that successful foragers are able to communicate the scent of the flowers from which they have been gathering food to other bees has led to attempts to direct honeybees to crops which need to be pollinated. The method used has been to feed syrup, containing the scents of the flowers of the crops requiring to be pollinated, to colonies of bees.

Foragers that are seeking food are attracted to flowers by their movement (Wolf, 1937) and by their colour and scent (Butler, 1951). Ribbands (1949) has demonstrated that when a honeybee knows of more than one source of food she appears to select the best

of these at any given time, and von Frisch (1946) has shown that she is able to communicate to other members of her colony the positions of any of these sources.

Close observations suggest that colonies of honeybees possess very effective methods of finding and exploiting the best of the crops within their foraging range, so that although it might be possible to mislead them into pollinating one of the poorer crops, no increase in honey yield could result from this procedure. However a colony's methods of finding the best crops available do not, in fact, appear to be as effective as one might expect them to be, as it has been noted that colonies in the same apiary will frequently collect the bulk of their food from very different sources (Synge, 1947). It has also been shown that colonies of bees that have been moved to a heather area before the heather flowers have opened, and have commenced to forage on other kinds of flowers, have failed to transfer their activities to the much more abundant heather flowers when these became available (Moore-Ede, 1947). It seems possible, therefore, that when colonies of bees are directed to crops to pollinate them their honey yields may occasionally be increased.

In early practical experiments to direct bees to crops Russian workers, such as Veprikov (1936), claim to have obtained considerable increases in the number of bees visiting the experimental crops and in the amount of seed produced. However, later investigations by von Frisch (1947) produced less definite results; in his experiments the number of honeybees foraging on the experimental crops appear almost invariably to have been increased, but the figures obtained for set of seed, and for seed yield at harvest, are less satisfactory. On crops other than red clover increased honey yields (allowance being made for the sugar fed) were obtained. In the case of red clover, however, the effects on honey yield were not significant. This suggests that although von Frisch was successful in directing the bees to red clover, they were unable to obtain any more nectar from these flowers than they would have done from others.

Von Frisch (1947) pointed out that directing bees to crops from which they cannot obtain nectar is not likely to result in much additional pollination of the crop. He, therefore, suggested that in such cases it might be possible, and more profitable, to attempt to direct pollen-gathering bees to the crop rather than nectar-gatherers, by feeding syrup scented with the pollen of its flowers. Unfortunately, experiments at Rothamsted to direct bees to red-clover crops, by feeding red-clover pollen in syrup, have produced no evidence that the proportion of pollen gathered from red-clover flowers can be increased by such treatment.

Von Frisch (1947) also showed that it is more effective to feed scented syrup to bees outside the hive than inside. Some unpublished observations by Butler suggest that this may be due to the very much greater tendency of bees that have collected food in the light to perform recruiting dances, and also that intermittent feeding is likely to be more effective than continuous feeding, as most of the dances are performed by the first few bees which visit the feeder.

V. Use of Honeybees as Pollinators in Particular Instances

(a) *Orchard pollination*

Brittain *et al.* (1933) have pointed out that the number of colonies of honeybees required to yield the necessary proportion of bees to flowers in an orchard depends on many factors, including, of course, the area of the orchard and also the amount of bee forage, other than that provided by the fruit-trees, available in and around the orchard. Butler (1948) recommended that a group of colonies should be placed in the centre of each 15–20 acres or orchard. Although the validity of the suggestion that this method of placing the colonies increases the degree of competition between the bees and also increases their tendency to wander from tree to tree, and thus to effect cross-pollination, has not yet been adequately demonstrated, there is no doubt that it possesses certain advantages. By keeping the colonies away from the edges of the orchards it probably reduces the tendency of the bees to forage outside them, and further it enables the grower to determine, over a period of time, the number of colonies of a given strength necessary to produce an adequate set of fruit, since if an insufficient force of bees is present the set of fruit falls off at some distance from the hives, and when an even set of fruit has been obtained throughout an orchard the force of bees is probably correct (Butler, 1942). Grouping of the colonies together is also advantageous to management both by the beekeeper and the grower. In spite of Ribbands' (1951) observations of the large diminution of foraging in bad weather with increased flying distance, it is unlikely that the method of locating colonies suggested by Butler (1948) will result in any serious diminution of foraging activity, since the radius of a circle of an area of 20 acres, in the centre of which it has been suggested that the colonies should be placed, is only 176 yards. Larger groupings, however, are undesirable.

(b) *Pollination in confined spaces*

Colonies of honeybees are sometimes used to cross-pollinate such crops as peaches in glass-houses (Thompson, 1940). Unfortunately, however, although honeybees have been found to be very satisfactory for such purposes, and to save much manual labour, the condition of the colonies used tends to deteriorate very rapidly and the foraging force to diminish during the first few days of confinement to the house, on account of many of the bees dying in attempts to escape. However, the young bees which replace the original foragers show a much reduced tendency to behave in this way.

Recently colourless nylon screen-cages have been found useful in work on the pollination of red clover and other crops, as well as for work on the breeding of brassica varieties. It has been found at Rothamsted that bees behave well in these cages and that normal plant growth is maintained within them. Indeed it seems probable that this type of cage may prove extremely valuable in plant breeding.

VI. References

Beutler, Ruth. (1953). Nectar. *Bee World*, **34**, 106–116, 128–136, 156–162.

Brittain, W. H. *et al.* (1953). Apple pollination studies in the Annapolis Valley, N. S. Canada. *Canad. Dep. Agric. Bull.*, 162 (new series), 198.

Butler, C. G. (1942). The honeybee. *Nature, Lond.*, **150**, 759.

Butler, C. G. (1943). The honeybee and the fruitgrower. *Fruitgrower*, **94**, 48.

Butler, C. G. (1945*a*). The influence of various physical and biological factors of the environment on honeybee activity. An examination of the relationship between activity and nectar concentration and abundance. *J. exp. Biol.*, **21**, 5.

Butler, C. G. (1945*b*). The behaviour of bees when foraging. *J. roy. Soc. Arts*, **93**, 501.

Butler, C. G. (1948). The importance of bees in orchards. *Min. Agric. & Fish. Advisory Leaflet*, 328.

Butler, C. G. (1949). *The honeybee: an introduction to her sense-physiology and behaviour*. Oxford Univ. Press.

Butler, C. G. (1951). The importance of perfume in the discovery of food by the worker honeybee (*Apis mellifera* L.). *Proc. roy. Soc. B.*, **138**, 403.

Butler, C. G., Finney, D. J. & Schiele, P. (1943). Experiments on the poisoning of honeybees by insecticidal and fungicidal sprays used in orchards. *Ann. appl. Biol.*, **30**, 143.

Butler, C. G., Jeffree, E. P. & Kalmus, H. (1943). The behaviour of a population of honeybees on an artificial and on a natural crop. *J. exp. Biol.*, **20**, 65.

Crane, M. B. & Mather, K. (1943). The natural cross-pollination of crop plants with particular reference to the radish. *Ann. appl. Biol.*, **30**, 301.

Dadant, M. G. (1951). Alfalfa seed—one thousand pounds per acre. *Amer. Bee J.*, **91**, 142.

Franklin, W. W. (1951). Insects affecting alfalfa seed production in Kansas. *Tech. Bull. Kansas agric. Exp. Sta.*, 70, 64.

Free, J. B. (1952). Robbing of red clover flowers by bumblebees. (Unpublished work.)

Frisch, K. von (1923). Ueber die "Sprache" der Bienen. *Zool. Jb., Abt.* 3, **40**, 1.

Frisch, K. von (1934). Ueber den Geschmackssinn der Biene. Ein Beitrag zur vergleichenden Physiologie des Geschmacks. *Z. vergl. Physiol.*, **21**, 1.

Frisch, K. von (1946). Die Tänze der Bienen. *Österr. Zool.* **1**, 1. (*Transl.* (1947) *Bull. Anim. Behav.* 5, 1).

Frisch, K. von (1947). *Duftgelenkte Bienen im Dienste der Landwirtschaft und Imkerei*. Wien, Springer.

Gubin, A. F. (1945). Cross-pollination of fibre flax. *Bee World*, **26**, 30.

Hammer, O. (1949). Om konkurrencen mellem blomstrende Afgrøder. *Ugeskrift før Landmoend*, 10.

Hammer, O. (1950). Biernes bestovningsarbejde og froudbyttets storrelse. *Tss. Froavl.*

Hirschfelder, H. (1951). Quantitative Untersuchungen zum Polleneintragen. *Bienenforsch*, **1**, 67.

Hutson, R. (1926). Relation of the honeybee to fruit pollination in New Jersey. *Bull. N. J. agric. Exp. Sta.*, 434.

Lindauer, M. (1952). Ein Beitrag zur Frage der Arbeitsteilung im Bienenstaat. *Z. vergl. Physiol.*, **34**, 299.

Menke, H. F. (1952). Alkali bee helps set seed records. *Crops & Soils*, **4**, 2.

Minderhoud, A. (1951). De plaatsvastheid van insecten in verband met de plantenveredeling. *Meded. Tuin.*, **14**, 61.

Moore-Ede, W. E. (1947). Some notes on bee behaviour. *Brit. Bee J.*, **75**, 448.

Müller, H. (1882). Versuche über die Farbenliebhaberei der Honigbiene. *Kosmos*, **12**, 273.

Oettingen-Spielberg, Therese (1949). Ueber das Wesen der Suchbiene. *Z. vergl. Physiol.*, **31**, 454.

Ribbands, C. R. (1949). The foraging method of individual honeybees. *J. anim. Ecol.*, **18**, 47.

Ribbands, C. R. (1951). The flight range of the honeybee. *J. anim. Ecol.*, **20**, 220.

RIBBANDS, C. R. (1953). *The behaviour and social life of honeybees.* Bee Research Assoc. Ltd.

RYLE, MARGARET (1954*a*). The influence of nitrate, phosphate and potash on the secretion of nectar. Part I. *J. agric. Sci.* (in the press).

RYLE, MARGARET (1954*b*). The influence of nitrate, phosphate and potash on the secretion of nectar. Part II. *J. agric. Sci.* (in the press).

SIMPSON, J. (1949). Foraging behaviour of honeybees on flax. (Unpublished work.)

SYNGE, ANNE D. (1947). Pollen collection by honeybees. *J. anim. Ecol.*, **16**, 122.

THOMPSON, F. (1940). The importance of bees in agriculture. *Bee Craft*, **22**, 6.

TYSDAL, H. M. (1940). Is tripping necessary for seed setting in alfalfa? *J. Amer. Soc. Agron.*, **32**, 570.

VANSELL, G. H. (1942). Factors affecting the usefulness of honeybees in pollination. *Circ. U.S. Dep. agric.* 650, 31.

VEPRIKOV, P. N. (1936). *The pollination of cultivated agricultural plants.* Moscow, Selkhozgiz.

WOLF, E. (1937). Flicker and the reactions of bees to flowers. *J. gen. Physiol.*, **20**, 511.

WYKES, GWENYTH R. (1952*a*). An investigation of the sugars present in the nectars of flowers of various species. *New Phytol.*, **51**, 210.

WYKES, GWENYTH R. (1952*b*). The influence of variations in the supply of carbohydrate on the process of nectar secretion. *New Phytol.*, **51**, 294.

WYKES, GWENYTH R. (1952*c*). The preferences of honeybees for solutions of various sugars which occur in nectar. *J. exp. Biol.*, **29**, 511.

WYKES, GWENYTH R. (1953*a*). The sugar content of nectars. *Biochem. J.*, **53**, 294.

WYKES, GWENYTH R. (1953*b*). The effect on nectar secretion of removing nectar from flowers. *Bee World*, **34**, 23.

PHYSICAL PROPERTIES AND CONTACT TOXICITY OF DDT AND SOME RELATED COMPOUNDS

By

A. H. McIntosh

Research on biologically active compounds, including insecticides, is often done by making a group of similar chemicals and testing them by some standard method. This may lead to the discovery of new insecticides. But the aim is sometimes to correlate chemical structure with toxicity in the hope of finding some general rule by which the toxicity of any chemical in the group may be foretold.

The physical as well as the chemical properties of a compound can affect its toxicity, and when chemical structure is changed, physical properties are nearly always changed as well; so that it may sometimes be misleading to relate toxicity directly to chemical structure unless changes in the important physical properties are small.

Some of the work done in the past few years at Rothamsted has been aimed at finding out what effect the physical form can have on toxicity, and what physical properties are desirable in an insecticide when it is applied directly to the insects' bodies. This work is academic, but may in the end have some effect on the way insecticides are made up for field use.

All the compounds we used are chemically related to DDT. They are all crystalline solids which do not dissolve in water. They are all contact poisons. This means that the insects can be killed without having to eat the poisons; contact with the insects' bodies is enough. None of the poisons give off vapours that can kill the insects.

Two or more types of aqueous suspensions were made with each compound. One type (colloid) contained very small particles of supercooled liquid poison, probably about 0·0001 mm. in size. The others contained crystals, often about 0·05 mm. These crystals were uniform, but the size varied from one compound to another; in some cases several different types of suspension were made of a single compound, each containing uniform crystals of characteristic size.

The toxicity of each suspension was found by a method which involves dipping saw-toothed grain beetles (*Oryzaephilus surinamensis*) for a few moments in the suspension (McIntosh, 1947*a*). After this the suspension is drained off, and the beetles are left with a coating of poison sticking to them. The dipping does not drown the insects; they are kept for 24 hours or more after dipping, and then counts are made to see how many have died from the poison. It is important that the temperature of the insects is kept constant during this time, because changes in temperature nearly always affect the kill.

In this way the suspensions were compared in pairs; a suspension of crystals of each poison was compared with the same poison in

colloidal form. This review discusses how the difference in toxicity between colloid and crystals may be related to the physical properties of the poison.

DDT was one of the compounds with which several different suspensions of crystals were made, each containing crystals of a different size. Crystals of DDT are needle-shaped or plate-shaped; the crystal size was varied from about 0·06 mm. to about 0·4 mm. When these suspensions were compared on grain beetles kept warm (27° C.) after dipping, the colloid was always the least toxic suspension; the longer the needles, the more toxic they seemed to be (McIntosh, 1946). The longest needles were about fifteen times more toxic than the colloid. This was unexpected, but the immediate cause was not hard to find. When the insects are taken from the suspension, poison sticks to them; it can be washed off, and the amount retained can be found by chemical analysis. This showed that the insects retain much more poison from a suspension of long needle-shaped crystals than from a suspension of colloidal particles. The extra dose received was in fact almost enough to account for the higher toxicity of the suspension of crystals (McIntosh, 1947*b*). Differences in toxicity amongst the other suspensions of DDT crystals can be explained in the same way; crystal size decides retention. Tests with other compounds besides DDT suggest that retention of this sort is purely mechanical. Retention by one insect species depends on crystal size only; different poisons with crystals of the same size are retained equally well. Plate-shaped crystals are not retained so well as needle-shaped crystals. Poorest retention was found with plate-shaped crystals of about 0·025 mm., and not with the very smallest particles. With some poisons there is no method for micro-analysis. In such a case the retention can be guessed by comparison with some other compound that gives analyzable crystals of the same size.

The results of all comparisons of toxicity by dipping must be corrected one way or the other to allow for differences in retention.

It may seem at first sight as if the results of the tests with DDT can be completely explained by differences in retention. This is not so. A very short description of what insect cuticle (skin) is like may make this clearer. Cuticles vary in structure from species to species, and even from one area of a single insect to another. But there is always a thin waxy layer on the very outside (Wigglesworth, 1948; Beament, 1948). The first thing a contact poison lying on the cuticle must do to get into the insect is to dissolve in this wax layer. Without this, nothing can happen to the insect. For this reason the need for a contact insecticide to be soluble in fat has often been stressed.

With DDT it is thought that there are certain spots on the cuticle surface which are more easily penetrated than the rest, or which form short-cuts to the site of action of DDT inside the insect (see, for instance, Schaerffenberg, 1949; Wiesmann, 1949; Fisher, 1952). Poison applied to them kills the insect more efficiently than the same amount of poison applied anywhere else. The wax covers the sensitive spots as well as the rest of the cuticle, and so the first step in penetration must be the same everywhere, whether the insect dies as a result or not.

The wax layer is very thin, and must soon become locally

saturated beneath and round about particles of poison that are in contact with it. If saturation can be kept up long enough, especially on a sensitive spot, the insect will die.

After insects have been dipped, the film of poison sticking to them becomes dry. With colloidal poison the film is not even, but takes the form, to begin with anyway, of little blobs of supercooled liquid poison. The chances of hitting a sensitive spot with a blob or with a crystal must be about the same. One might naturally expect that the poison from the blobs would dissolve more quickly in the wax than the poison from the crystals; colloidal poison should be more toxic than crystals, or should act more quickly. However, the two forms of DDT are in fact almost equally toxic.

Counts of kill are usually made one or two days after treatment. The choice is largely one of convenience. But it did not seem to matter whether they were made after 1½ hours or 72 hours; the ratio of toxicities was always the same (McIntosh, 1949). So we have the unexpected fact that the speeds of solution of the two forms of DDT in wax are, as far as can be judged from the biological tests, nearly the same. Speed of solution does not seem to decide speed of kill.

What has been said so far applies to insects that are kept warm (27° C.) between dipping and counting. If the insects are treated with the same two forms of DDT and then kept cool (11° C.) instead of warm, the relative toxicity is reversed; the colloid is now more toxic than the crystals by about the same amount as it is less toxic to the warm insects. Tests by injection of suspensions into larger insects give similar results, and suggest that the difference in toxicity at 11° C. is largely a difference in speed of action; if the injected insects are kept cool for long enough, the kill from the crystals catches up on the kill from the colloid (McIntosh, 1951*a*). The process of dissolving is slowed down in cool insects, but it is slowed down more for the crystals than for the colloid. The physical theory of very small particles supports the idea that they should be relatively more toxic at lower temperatures (McIntosh, 1951*b*).

One effect of cooling the insects is to accentuate the difference in speeds of action between small and large particles, making it easier to measure. Other compounds related to DDT behave in somewhat the same way when tested as contact poisons on *O. surinamensis* kept cool after treatment. The colloidal form is always more toxic than crystals, but the size of the difference in toxicity varies from one analogue to another.

Two properties of dissolving materials might be expected to affect this difference in toxicity.

Firstly, the deposits left by the colloidal poisons are made up of globules to begin with, but often crystallize later. The speed at which this happens varies from compound to compound, and can be measured in *in vitro* tests. If the deposit crystallizes quickly, it is soon not very different from the deposit left by a suspension of crystals; the difference in toxicity between colloid and crystals is likely to be small.

Secondly, if it is in fact necessary for poison to saturate the wax layer, then the speed at which a poison can dissolve in the wax may be more important than the solubility itself. It is possible to measure

the time it takes for crystals of a poison to bring about saturation of olive oil *in vitro*. This figure was taken as a guide to their speed of solution in insect wax. It was not possible to measure the speed of solution of deposits from colloidal poisons in olive oil; they dissolve quickly, and it was assumed that they all dissolve at the same speed. Different poisons with crystals of the same size do not necessarily bring about saturation at the same speed. If the crystals dissolve slowly, the difference in toxicity between colloid and crystals is likely to be large.

When allowance is made for differences in retention, the analogues fall into two groups. Each compound in the first group shows a difference in toxicity of about eight times; the colloid is about eight times more toxic than the crystals if counts are made one day after treatment. In the second group the differences in toxicity between colloid and crystals are very much bigger; the values found lie between thirty and eighty.

It was said that if a compound gives a slowly-crystallizing deposit from colloid *or* gives crystals that dissolve slowly, the difference in toxicity may be large. But the tests showed that each of the compounds giving a large difference in toxicity had *both* these qualities. One was not enough. The reason why both should be necessary is not clear. It may be that this is not a general rule; one quality or the other, if extreme enough, might produce a large difference in toxicity.

The lipoid-solubility, or solubility in fats, is often said to be important in deciding the toxicity of a contact insecticide. The implication, sometimes stated directly, is that in a group of very similar compounds like close analogues of DDT the most soluble compounds are the best contact insecticides (Martin & Wain, 1944; Browning *et al.*, 1948; Skerrett & Woodcock, 1952). It is certainly not true with this group of DDT analogues. They are all fat-soluble, but there is no relation at all between the toxicity (of colloid) and solubility in olive oil, which is often taken as a convenient measure of solubility in body fat. The difference in toxicity between colloid and crystals is not related to fat-solubility either.

The reactions of the insects to different sizes of particle seem to support the idea that the first step in penetration is solution of poison in some solvent, presumably the cuticle wax. It may seem rather obvious that it is better to use colloid than crystals, and that the qualities making for efficiency are slow crystallization of supercooled poison if it is applied as a colloid, and quick solution of crystals if the poison is applied as a solid. But the tests of DDT on warm and cool *O. surinamensis*, and of the other analogues, suggest that with this species the qualities that affect speed of solution do not decide speed of kill if the insects are kept warm after treatment; they are important only if the temperature is low. These qualities ought to apply to some extent to any stable contact insecticide and to almost any species of insect; this has still to be confirmed. The temperature at which they become important will not necessarily be the same for different species.

Crystallization of DDT can be prevented by mixing other compounds with it. This kind of non-crystalline DDT is more toxic than pure DDT in tests of dusts on sheep keds or vinegar flies (Riemschneider, 1950), and in tests of films on mosquitoes

or DDT-resistant houseflies (Ascher, Reuter & Levinson, 1951; Ascher & Reuter, 1953). In the film tests the non-crystalline DDT may stick better to the insects than crystals do, and for this reason may seem to be more toxic. But Beran (1952) found that impure non-crystalline DDT is more toxic than pure crystalline DDT when equal amounts are applied directly to houseflies. In all these tests the insects were kept warm (24–28° C.) after the poison was applied. From this it seems more likely that a low crystallization tendency is in general a helpful property at all temperatures and not just at low ones.

In practice it will seldom be possible to apply solid contact poisons in colloidal form. They are often formulated in one crystalline form or another. If a poison is to be efficient it must be able to saturate the cuticle wax quickly. This may be the result of its own properties, or of formulation; but in either case attention should be given to speed of solution rather than fat-solubility, which has perhaps been over-emphasized in the past. Some degree of fat-solubility is certainly necessary, but it need not be very high.

References

Ascher, K. R. S. & Reuter, S. (1953). *Riv. Parassit.*, **14**, 115.

Ascher, K. R. S., Reuter, S. & Levinson, Z. (1951). *Advances in insecticide research.* Jerusalem.

Beament, J. W. L. (1948). *Disc. Faraday Soc.*, **3**, 177.

Beran, F. (1952). *Meded. LandbHogesch. Gent*, **17**, 203.

Browning, H. C., Fraser, F. C., Shapiro, S. K., Glickman, I. & Dubrûle, M. (1948). *Canad. J. Res. D*, **26**, 282.

Fisher, R. W. (1952). *Canad. J. Zool.*, **30**, 254.

McIntosh, A. H. (1946). *Nature, Lond.*, **158**, 417.

McIntosh, A. H. (1947*a*). *Ann. appl. Biol.*, **34**, 233.

McIntosh, A. H. (1947*b*). *Ann. appl. Biol.*, **34**, 586.

McIntosh, A. H. (1949). *Ann. appl. Biol.*, **36**, 535.

McIntosh, A. H. (1951*a*). *Ann. appl. Biol.*, **38**, 567.

McIntosh, A. H. (1951*b*). *Ann. appl. Biol.*, **38**, 881.

Martin, H. & Wain, R. L. (1944). *Nature, Lond.*, **154**, 512.

Riemschneider, R. (1950). *Z. angew. Ent.*, **31**, 431.

Schaerffenberg, B. (1949). *Z. PflKrankh.*, **56**, 37.

Skerrett, E. J. & Woodcock, D. (1952). *J. chem. Soc.*, 3308.

Wiesmann, R. (1949). *Mitt. schweiz. ent. Ges.*, **22**, 257.

Wigglesworth, V. B. (1948). *Disc. Faraday Soc.*, **3**, 172.

RECENT WORK ON MOLYBDENUM AND SOME MICRO-NUTRIENT INTERACTIONS

By
K. Warington

Introduction

Since 1941–42, when the effect of various incidental constituents of Chilean nitrate were being studied, micro-nutrient investigations in the Botany Department at Rothamsted have been largely concerned with molybdenum. This element is the most recent to be shown essential for higher plants, and not until 1939 did Arnon and Stout prove it essential for tomato. Piper (1940), Hoagland (1941) and Warington (1946) followed with oats, plum and lettuce respectively, and proof has now been extended to a number of other crops. It was from field experiments in Southern Australia and Tasmania, however, that the practical importance of the element first came to be appreciated, Anderson (1942) and Fricke (1943) demonstrating that failure of subterranean clover on certain ironstone soils was due to molybdenum deficiency. The discovery in New Zealand (Davies, 1945, and Mitchell, 1945) that whiptail disease of cauliflower was caused by molybdenum deficiency soon followed, confirmation of the field symptoms being obtained in sand culture by Hewitt and Jones (1947).

Molybdenum Deficiency

Among the points established during the course of the earlier field trials was the greater availability of molybdenum under alkaline conditions (Stephens and Oertel, 1943) a fact to which Fricke (1944) attributed the benefit he obtained from the addition of lime only on soils responding to molybdenum dressings. These results fall into line with those of Ferguson, Lewis and Watson at Jealott's Hill (1940), who had found that liability to " teartness " in cattle, caused by excess molybdenum in the herbage of pastures in Somerset, was increased by a rise in soil pH.

The notable response of legumes to molybdenum and the observation that molybdenum-deficient clover was invariably pale, led to enquiries regarding the effect of this element on nitrogen fixation by the nodule organism. Bortels (1930) had already shown that molybdenum was needed for normal growth of *Azotobacter* in culture media lacking nitrogen, and Steinberg (1936) that it was required for nitrate reduction by *Aspergillus*. Jensen and Betty (1943) recorded increased nitrogen content in the roots of molybdenum-treated lucerne and white clover, and high concentrations of the element in their nodules, while in 1946 Anderson and Thomas followed with proof that molybdenum was essential for symbiotic nitrogen fixation. Mulder (1948) confirmed Steinberg's results and showed in addition that molybdenum was required for nitrate reduction in higher plants of a non-leguminous type and also for denitrification. Hewitt, Agarwala and Jones (1950) further found

that ascorbic acid production was much diminished by a lack of molybdenum.

Since the beneficial effect of liming suggested that response to molybdenum might be influenced by the calcium supply or the pH of the substrate, and one function of the element at least seemed to be connected with nitrogen nutrition, the next series of solution cultures at Rothamsted were designed to study the effect of these three factors (Warington, 1950). Here the amount of calcium supplied was found to have a marked effect on growth of both lettuce and red clover, more being required as acidity increased, but the level provided had no influence on the response of either plant to molybdenum. Variation in initial pH value (4·2–8·2), with calcium at a uniform standard rate, also affected growth very noticeably, in spite of a rapid levelling up in the reaction of the solutions, but with the possible exception of the most alkaline medium, visual molybdenum deficiency symptoms were invariably obtained unless molybdenum was provided. Response to molybdenum occurred with both species at all levels of nitrogen tried, and in both inoculated and uninoculated clover, the number of nodules formed in the latter set being greater when molybdenum was lacking, as described by Anderson and Thomas (1946). Nitrate-nitrogen accumulated in the shoots of the molybdenum-deficient lettuce and clover shoots confirming the results of Mulder (1948) and Hewitt, Jones and Williams (1949). There was also some indication that lettuce was more liable to damage from excess molybdenum when the nitrate supply was raised, an effect in keeping with the results of subsequent pot experiments (Brenchley, 1948).

Molybdenum Excess

(a) *Microscopic effects*

Prior to the discovery that molybdenum was essential in plant nutrition, Sheffield (1934), working at Rothamsted, had found that addition of salts of molybdic acid induced changes in cell contents of solanaceous plants, inclusion bodies similar to those resulting from virus infection being formed. The nature of the compound, however, was not determined. Later microchemical tests, carried out on tissue from potato tubers and tomato shoots of plants grown with toxic quantities of molybdenum, showed that the characteristic golden colour developed under these conditions was caused by globular yellow bodies of a tannin–molybdenum complex (Warington, 1937). In the tomato, blue granular compounds of molybdenum with anthocyanin were also detected. A form of leaf mottling appeared on the leaves of tomatoes suffering from excess molybdenum, simulating virus symptoms, but subsequent inoculation tests showed that the plants were free from disease.

(b) *Macroscopic effects*

Most plants show high tolerance to molybdenum, and herbage containing amounts sufficient to cause " teart " disease of cattle remains undamaged itself. The species comprising the pastures, however, vary widely in their capacity to absorb the element, clovers and Yorkshire fog in particular showing much higher contents than the other grasses or weeds growing on the same soil

(Ferguson, Lewis and Watson, 1950). Tolerance to molybdenum also depends on the nature of the soil as well as the crop, Brenchley (1948) finding that dressings harmless to tomatoes grown on loam or allotment soil were very toxic on sandy Woburn soil. Further, *Solanum nodiflorum* was uninjured on allotment soil by a dressing which proved lethal to it on a cucumber soil rich in nitrogen, and while flax suffered considerable damage on this latter soil, tomato treated with the same rate of molybdenum on it remained unharmed. Other soil properties as well as nitrogen content and pH value would, therefore, seem to be factors determining uptake of molybdenum. HCl-soluble iron may also be of importance, for of thirteen Australian soils tested, Williams and Moore (1952) found least molybdenum absorbed by oats when the soil was rich in iron, the differences reaching significance independent of pH value.

Interactions between Molybdenum and other Elements

It is generally recognized that interaction between the various major and minor elements are of paramount importance, and much recent work with molybdenum has dealt with this aspect. From pot and field experiments (1948, 1949*a*), Millikan concluded that manganese and molybdenum were antagonistic, and showed later (1951) that addition of high concentrations of molybdenum to flax grown with excess manganese reduced the manganese content and altered its distribution, while Anderson and Spencer (1950) found that manganese accentuated molybdenum deficiency in clover and lowered its uptake.

Earlier Millikan (1947) had shown that molybdenum, if presented in sufficiently high concentrations, could counteract chlorosis induced in flax by a number of heavy metals given in toxic amounts. Hewitt (1949), on the other hand, found molybdenum enhanced the chlorotic symptoms of metal excess in sugar beet. He considered that some aspect of nitrogen nutrition was probably involved whichever way the interaction worked, and Bennett (1945) had already put forward the view that chlorosis was a disturbance of nitrogen as well as of iron metabolism.

The possibility that vanadium might give similar results to molybdenum seemed worth investigating, for Horner *et al.* (1942) had shown that the two elements could replace each other in *Azotobacter* nutrition, though Vanselow and Datta (1949) found no evidence for this in citrus. Comparison was, therefore, made of the effects of high concentrations of molybdenum or vanadium in the presence of manganese excess (Warington, 1951). Flax and soybean were grown in nutrient solutions containing manganese at toxic (10–25 p.p.m.) and non-toxic (1 p.p.m.) levels, each combined with a range of concentrations of molybdenum or vanadium. Relatively high rates were required before any interaction with manganese was obtained, and the effects of the two elements were contrasting. Molybdenum (20 p.p.m. and to a less extent 10 p.p.m.) intensified the chlorosis induced by high manganese as Hewitt (1949) found with sugar beet, but both rates of molybdenum proved harmless in the presence of only 1 p.p.m. manganese.

Vanadium (equivalent to 1·0 or 5 or 10 p.p.m. Mo), on the other hand, counteracted some of the symptoms of manganese toxicity,

suppressing at least temporarily the apical chlorosis of both crops and reducing the leaf curling in soybean, though eventually the higher levels of vanadium induced apical chlorosis on their own account. Vanadium equivalent to only 0·1 p.p.m. Mo, however, failed to exert any noticeable effect at all. Thus, under this set of experimental conditions, high vanadium gave results similar to those obtained by Millikan for high molybdenum (1947) and later by him for aluminium also (1949*b*).

Interactions between Various Metals and Iron

(a) *Visual effects*

That metal toxicity causes disturbances in iron nutrition is no new discovery, for in 1919 Johnson cured pineapples suffering from excess manganese by spraying with iron. Similar antidoting effects of iron on other metals in excess have been found by various authors using either additions of iron to the nutrient medium or external applications to the leaves. Counteraction of metal toxicity by elements other than iron has, however, only recently been claimed. Since vanadium was one of the elements possessing this property, information regarding its effect on plants suffering from a direct (as distinct from metal-induced) shortage of iron seemed desirable. Ferric citrate was used as a source of iron, the standard amount selected as control depending on the crop grown. Within the concentrations tried (0·05–5 p.p.m. V) vanadium failed to relieve iron-deficiency chlorosis in soybean or flax, 2·5 or 5 p.p.m. V in fact proving more toxic if the iron content of the solution was reduced to one-half or one-third of the control (10 p.p.m. Fe) (Warington, 1954). Increasing the iron to 20 p.p.m., on the other hand, almost removed the symptoms of vanadium excess in peas in both root and shoot, and similar, though less-pronounced, effects were obtained with flax. Injury from manganese and molybdenum excess was similarly reduced by an increase in the iron provided, but if two or more of these elements were presented together the same quantity of iron was less efficient in counteracting their toxicity. This suggested that their effects towards iron were additive. The method of supplying the iron was important, for the same total amount given gradually proved less capable of offsetting the damage from vanadium and molybdenum than when supplied in a single initial dose. This, however, did not hold for manganese. Identical changes in the level of iron supplied had little or no effect in the presence of low concentrations of these elements, though there were indications, confirmed later, that there was a limit to the amount of iron that could be given without causing injury. Damage to citrus from excess iron has been described by Smith and Specht (1953), who, moreover, found it could be offset by application of high copper, zinc or manganese. A similar compensating effect of high molybdenum on excess iron has been found in flax (Warington, unpublished).

(b) *Effects on plant composition*

Attempts to interpret these interactions between manganese, molybdenum, vanadium and iron necessarily include a study of the changes in plant content of the elements concerned, though visual

differences may occur without any corresponding change in plant composition. Chlorosis, for example, is not always accompanied by a reduction in iron content of the shoot. McGeorge (1949) found a correlation between chlorosis and the soluble fraction of iron only, though Smith, Reuter and Specht (1950) showed that it held for total iron if the material was washed with a detergent. Absence of any correlation was interpreted by Millikan (1949*a*) as indicating a lack of utilization of iron within the plant rather than to a reduction in uptake. Analyses of soybean shoots (Warington, 1954) showed that the total iron content was scarcely affected by the quantity of iron supplied (5–20 p.p.m. Fe) provided manganese, molybdenum and vanadium were present at a low rate, but it was much reduced by high concentrations of all three elements. On the other hand, there was little change in the iron found in the shoots of flax grown with high vanadium. Berger and Gerloff (1947) and Sideris (1950) also record a drop in iron content of shoots of potato and pineapple respectively on the addition of high manganese. Sideris attributed this to interference with translocation and immobilization of iron in the root, as there was no indication of external precipitation, a view supported by Epstein and Stout's results (1951). Smith and Specht (1953) have described similar inhibitory effects on movement of iron within the plant following the addition of high copper or zinc.

The manganese and vanadium contents of the soybean shoots, already referred to, fell sharply as the iron supply was increased, in agreement with the results of Twyman (1951) and Morris and Pierre (1947) for manganese. Reduction in molybdenum content, however, was less clearly shown, in spite of the fact that visual toxic symptoms had been counteracted by the additional iron. The method whereby the iron offsets metal toxicity thus appears at first sight to be a reduction in the amount of injurious metal in the shoot. This does not explain the recovery of colour following the application of iron paints or sprays, and it seems more likely that some interaction between the heavy metal and iron takes place in the root, resulting in changes in translocation of both iron and metal. Further analytical work will be needed before any definite conclusions can be drawn.

Other Factors affecting Metal Toxicity

The degree of injury caused by molybdenum, manganese and other elements also depends on the nature of the nitrogen supply. Millikan (1950) found manganese more toxic with nitrogen supplied as nitrate than as ammonia; the reverse was true for molybdenum. Further, ammonium molybdate proved more toxic than the sodium salt in the presence of nitrate, though both were equally damaging if the nitrogen was given in the form of ammonia or urea. Response to iron was also influenced by the form in which the molybdenum was provided, ammonium molybdate proving more efficient in overcoming iron deficiency than the sodium salt (Millikan, 1950; Warington, unpublished). That the incidence of chorosis is affected by many other factors such as potash supply, light, temperature, age of plant, etc., only adds to the complexity of the problem.

Conclusions

The ultimate aim of all investigations with micro-nutrients is to determine their function in plant nutrition. Information on this point is at present scanty. Approached from the point of view of deficiency, manganese, molybdenum, copper and zinc each appear to be associated with specific plant processes. If given in excess, these four elements may either cause disturbances in iron nutrition similar to each other and to those induced by metals not yet considered essential, (e.g., vanadium, nickel and cobalt) or exhibit antagonistic properties according to circumstances. The health of the plant seems to depend as much on a correct balance between the nutritive elements as on the presence of each, and precise statements regarding demand or tolerance for any particular micro-nutrient are, in consequence, of limited value only. Much further work will be needed before these metal interrelationships are fully understood.

References

Anderson, A. J. (1942). *J. Aust. Inst. agric. Sci.*, **8**, 73.
Anderson, A. J. & Spencer, D. (1950). *Aust. J. sci. Res.*, **3B**, 414.
Anderson, A. J. & Thomas, M. P. (1946). *Bull. Coun. sci. industr. Res.*, 198.
Arnon, D. I. & Stout, P. R. (1939). *Plant Physiol.*, **14**, 599.
Bennett, J. P. (1945). *Soil Sci.*, **60**, 91.
Berger, K. C. & Gerloff, G. C. (1947). *Proc. Soil Sci. Soc. Amer.*, **12**, 310.
Bortels, H. (1930). *Arch. Mikrobiol.*, **1**, 333.
Brenchley, W. E. (1948). *Ann. appl. Biol.*, **35**, 139.
Davies, E. B. (1945). *Nature, Lond.*, **156**, 392.
Epstein, E. & Stout, P. R. (1951). *Soil Sci.*, **72**, 47.
Ferguson, W. S. Lewis, A. H. & Watson, S. J. (1940). *Bull. Jealott's Hill Res. Sta.*, 1.
Fricke, E. F. (1943). *Tasm. J. Agric.*, **14**, 69.
Fricke, E. F. (1944). *Tasm. J. Agric.*, **15**, 65.
Hewitt, E. J. (1949). *Rep. Long Ashton Res. Sta.*, 1948, p. 66.
Hewitt, E. J., Agarwala, S. C. & Jones, E. W. (1950). *Nature, Lond.*, **166**, 1119.
Hewitt, E. J. & Jones, E. W. (1947). *J. Pomol.*, **23**, 254.
Hewitt, E. J., Jones, E. W. & Williams, A. H. (1949). *Nature, Lond.*, **163**, 681.
Hoagland, D. R. (1941). *Proc. Amer. Soc. hort. Sci.*, **38**, 8.
Horner, C. K., Burk, D., Allison, F. E. & Sherman, M. S. (1942). *J. agric. Res.*, **65**, 173.
Jensen, H. L. & Betty, R. C. (1943). *Proc. Linn. Soc. N.S.W.*, **68**, 1.
Johnson, M. O. (1919). *Rep. Hawaii agric. Exp. Sta.*, 1918, p. 23.
McGeorge, W. T. (1949). *Tech. Bull. Arizona agric. Exp. Sta.*, 117.
Millikan, C. R. (1947). *J. Aust. Inst. agric. Sci.*, **13**, 180.
Millikan, C. R. (1948). *Nature, Lond.*, **161**, 528.
Millikan, C. R. (1949*a*). *J. Dep. Agric. Vict.*, **47**, 37.
Millikan, C. R. (1949*b*). *Proc. roy. Soc. Vict.*, **61**, (N.S.), 25.
Millikan, C. R. (1950). *Aust. J. sci. Res.*, **3B**, 450.
Millikan, C. R. (1951). *Aust. J. sci. Res.*, **4B**, 28.
Mitchell, K. J. (1945). *N. Z. J. Sci. Tech.*, **27**, 287.
Morris, H. D. & Pierre, W. H. (1947). *Proc. Soil Sci. Soc. Amer.*, **12**, 382.
Mulder, E. G. (1948). *Plant & Soil*, **1**, 94.
Piper, C. S. (1940). *J. Aust. Inst. agric. Sci.*, **6**, 162.
Sheffield, F. M. L. (1934). *Ann. appl. Biol.*, **21**, 430.
Sideris, C. P. (1950). *Plant Physiol.*, **25**, 307.
Smith, P. F., Reuther, W. & Specht, A. W. (1950). *Plant. Physiol.*, **25**, 496.
Smith, P. F. & Specht, A. W. (1953). *Plant Physiol.*, **28**, 371.
Steinberg, R. A. (1936). *J. agric. Res.*, **52**, 439.
Stephens, C. G. & Oertel, A. C. (1943). *J. Coun. sci. ind. Res. Aust.*, **16**, 69.

Twyman, E. S. (1951). *New Phytol.*, **50**, 210.
Warington, K. (1937). *Ann. appl. Biol.*, **24**, 475.
Warington, K. (1946). *Ann. appl. Biol.*, **33**, 249.
Warington, K. (1950). *Ann. appl. Biol.*, **37**, 607.
Warington, K. (1951). *Ann. appl. Biol.*, **38**, 624.
Warington, K. (1954). *Ann. appl. Biol.*, **41**, 1.
Williams, C. H. & Moore, C. W. E. (1950). *Aust. J. agric. Res.*, **3**, 343.
Vanselow, A. P. & Datta, N. P. (1949). *Soil Sci.*, **67**, 363.

PUBLICATIONS

Physics Department

1. Emerson, W. W. & Grundy, G. M. F. (1954). The effect of rate of wetting on water uptake and cohesion of soil crumbs. *J. agric. Sci.*, **44**.

Short columns of air-dry soil crumbs were wetted at different rates and, after draining to a standard suction, the amount of water taken up by each column determined. It was found that this increased continuously with rate of water application. The corresponding progressive decrease in the cohesion of the wetted crumbs has been measured by their resistance to break down under the impact of falling water drops. By developing this into a rapid and sensitive method, it has been found that the loss of cohesion is due almost entirely to entrapped air, non-uniform swelling of the clay being a negligible factor in weakening crumbs.

The aggregates investigated were taken from adjacent fields differing only in their cropping treatment; one being under continuous arable and the other under continuous grass. The extrapolated value of the cohesion of the grassland crumbs at zero rate of wetting was twice that of the arable, indicating an additional cohesive force in the grassland crumbs. The cohesion of the arable soil fell much more rapidly with increased rate of wetting than that of the grassland, probably because the roots in the grassland crumbs provide easy escape passages for the air.

The increase, with rate of wetting, of the amount of water held by a soil sample against a given suction is important, at least up to 200 cm. of water. This dependence of the pF curve on rate of wetting is of particular significance for laboratory studies of water movement in soils.

2. Hirst, J. M., Long, I. F. & Penman, H. L. Micro-meteorology in the potato crop. *Proc. Toronto Met. Conf.* **1953**. (In the press. To be published by Royal Met. Soc., London. For summary see 99.)

3. Penman, H. L. (1952). Water and plant growth. *Agric. Progress*, **27**, 147.

In this survey of the causes of the need of plants for water a number of principles emerge, some based on reasonable certainty, others a little less certain and yet others are frankly speculative. Two statements are made and accepted as almost axiomatic. They are :

> When water supply is non-limiting the plant's rôle in transpiration is the passive one of providing a conducting channel between the soil and the atmosphere.
>
> Maximum transpiration is a necessary condition for maximum growth. It may not be a sufficient condition.

The basic principles are :

> When water supply is non-limiting the transpiration rate is determined by prevailing weather.
>
> Apart from minor effects, this rate, known as the potential transpiration rate, is the same for all short crops of about the same colour and completely shading the ground.
>
> The potential transpiration rate is less than the evaporation rate from an open water surface exposed to the same weather. The open-water evaporation rate can be estimated from weather data.

Principles still in evolution include :

> Potential transpiration is less than open-water evaporation because : (i) the stomata impede the flow of vapour; (ii) transpiration opportunity is largely restricted to daylight, and so varies with season and latitude. As a rider : an empirical conversion factor has proved widely useful in a variety of applications, including the control of irrigation operations.
>
> A modified treatment is needed for crops where ventilation between

plants is possible. The most important case is an extreme, namely in an open orchard. A first attack on this problem has met with success.

The following are somewhat more speculative :

Each type of crop has a root constant, which is the amount of water that can be transpired at the potential rate.

This constant is largely independent of the type of soil, but will depend on the stage of biological development of the plant, and may be modified by the weather cycle or crop management.

4. Schofield, R. K. & Samson, H. R. (1953). The deflocculation of kaolinite suspensions and the accompanying change-over from positive to negative chloride adsorption. *Clay Min. Bull.*, **2**, 45.

Pure kaolinite washed first with 1*M*-NaCl containing 0·001*M*-HCl and then with distilled water remains firmly flocculated when salt free. In this state the kaolinite retains exchangeable Na, which shows that the crystals are negatively charged.

When re-dispersed in 0·005*M*-NaCl, the crystals positively adsorb chloride, which proves that parts of their surfaces (presumably the edge faces) are positively charged. The attraction of the positive charges on the edge faces for the negative charges in the body of the crystals is regarded as the cause of the flocculation which occurs in the absence of salt.

Deflocculation of the salt-free suspension occurs on the addition of a small but sufficient amount of NaOH. When kaolinite so treated and then air-dried is re-dispersed in 0·005*M*-NaCl, the crystals negatively adsorb chloride, showing that the edge faces are no longer positively charged.

Deflocculation can also be brought about by adding small amounts of sodium oxalate, sodium pyrophosphate, sodium polymetaphosphate, sodium alginate and sodium bentonite. Regardless of the agent used, when the kaolinite is deflocculated in the absence of free salt, the crystals repel chloride ions when placed in dilute NaCl.

An explanation of the variation of the charge on edge faces with pH is put forward based on the crystal structure of kaolinite, coupled with the idea that a small degree of isomorphous replacement gives rise to a permanent negative charge.

Chemistry Department

General Papers

5. Cooke, G. W. (1953). Fertilizer placement for threshed peas. *British Fmr.*, February, p. 3.

6. Cooke, G. W. & Chalmers, G. R. (1953). Placement drills are costly—but they pay. *Fmr. & Sth.-Breed.*, 24th February, p. 65.

7. Cooke, G. W. (1953). Are compound fertilizers worthwhile? *Grower*, **39**, (12), 583.

8. Crowther, E. M. (1952). The evaluation of soil fertility. *Trans. Joint Meeting of Commissions II and IV, Intern. Soc. Soil Sci. Dublin*, 2, 14.

General lecture given at the Opening Session of a joint meeting of the Commissions for Soil Chemistry and Soil Fertility and Plant Nutrition, reviewing some of the obstacles to applying what is known and to obtaining new knowledge.

Research Papers

9. Bremner, J. M. (1954). A review of recent work on soil organic matter. Part II. *J. Soil Sci.* (In the press.)

A review of recent work on the extraction and fractionation of soil organic matter, the interaction of organic and inorganic soil colloids, the humic and fulvic fractions and the lignin-like complexes of soil organic matter.

10. Bremner, J. M. (1953). Identification of hydroxylamine and hydrazine by paper chromatography. *Analyst.* (In the press.)

A method for the separation and identification of microgram quantities of hydroxylamine and hydrazine is described. It involves paper chromatography with acidic solvents and identification by R_F values and by the colours produced with picryl chloride and other detecting reagents.

11. Bremner, J. M. & Shaw, K. (1953). Studies on the estimation and decomposition of amino sugars in soil. *J. agric. Sci.* (In the press.)

The amounts of amino sugar-N present in acid hydrolysates of six soils with nitrogen contents ranging from 0·17 to 2·82 per cent have been estimated by colorimetric and alkaline decomposition methods. Recovery of amino sugar-N after hydrolysis of chitin or glucosamine was found to be unaffected by the presence of soil during hydrolysis. Substances known to interfere with the methods of amino sugar analysis employed were not detectable in the soil hydrolysates. From the amounts of amino sugar-N liberated by acid hydrolysis it is deduced that 5–10 per cent of the total nitrogen of the soils examined was in the form of amino sugars. The decomposition of amino sugars in soils has been studied by comparing the rates of decomposition of chitin, glucosamine, casein and yeast nucleic acid when incubated with soil under conditions found to produce rapid nitrification of ammonium sulphate. Glucosamine and chitin are readily decomposed by soil micro-organisms, but not so rapidly as casein or yeast nucleic acid.

12. Chambers, W. E. (1953). Nutrient composition of the produce of the Broadbalk continuous wheat experiment. Part I. Changes over seventy years. *J. agric. Sci.*, **43**, 473.

A rapid extraction procedure of dried ground plant material was used in conjunction with the Lundegårdh flame method of spectrographic analysis and its accuracy shown to be comparable with that for ashing with gravimetric analyses. The effects of fertilizer treatments on yield and nutrient composition of the crops and their changes with time were summarized. The recovery of potassium was estimated, and it was shown that the exhaustion or accumulation of soil potassium was related to the exchangeable potassium contents of the soils, but that the net gains or losses of potassium were many times greater than those found in the exchangeable or readily soluble potassium of the surface soils. Sodium or magnesium sulphates increased crop yields by increasing the supply of potassium from non-exchangeable forms.

13. Chambers, W. E. (1953). Nutrient composition of the produce of the Broadbalk continuous wheat experiment. Part II. Changes occurring during one season's growth. *J. agric. Sci.*, **43**, 479.

Throughout a season the total uptake of nutrients increased to a maximum and then decreased. The losses of potassium and magnesium from the stems and leaves were particularly large due to translocation to the ears, but there were also net losses of potassium and calcium from the plant. The changes were similar for all fertilizer treatments. The composition of the crop at harvest reflected its composition throughout the season.

14. Cooke, G. W. (1953). The correlation of easily-soluble phosphorus in soil with responses of crops to dressings of phosphate fertilizers. *J. Sci. Fd. Agric.*, No. 8, p. 353.

When sufficient numbers of soils are examined empirical determinations of easily-soluble soil phosphate can be used to forecast crop responses to fertilizer dressings. Correlations between soil analyses and crop behaviour fail for individual soils, and the causes have been examined.

Dilute acids dissolve relatively large quantities of phosphate from some soils where crops respond to phosphate fertilizers owing to: (1) dissolution of iron and aluminium phosphates; (2) use of too much solvent; (3) use of an unsuitable solvent; and (4) dissolution of phosphate from the interior of particles of calcium carbonate in calcareous soils.

Other soils contain very little phosphate soluble in dilute acid, but, nevertheless, crops grown on them do not respond to phosphate fertilizers. In

such cases crop growth may be limited by some other factor, such as drought. Phosphate dissolved by dilute acids is immediately reprecipitated by some soils; the extent of such reactions may be estimated by repeated extractions in the presence of added phosphate. Most mineral soils in eastern England fix very little phosphate during acid extraction, but fen soils and ferruginous soils may fix considerable amounts.

Changes in the amounts of soil phosphate that are soluble in dilute acid may occur when air-dried soils are stored. Such changes are accentuated by incubating moist soils with or without calcium hydroxide. Incubation experiments may be used to forecast increases in dilute-acid-soluble phosphate that occur during the growing period of crops and changes which occur in easily-soluble phosphate when acid soils are limed. Incubation with lime was used to measure reserves of soil phosphorus that were easily converted into forms soluble in dilute acids; such measurements were more satisfactory than simple extraction with dilute acid in relating crop responses and soil-phosphorus status in one group of field experiments.

15. Cooke, G. W. (1954). Designs of fertilizer distributors and their mechanisms. *J. Inst. Brit. Agric. Engng.* (In the press.)

The types of mechanisms used in commercial distributors are described and classified as: (1) gravity feed (unassisted); (2) assisted gravity feed; (3) metered gravity feed; (4) top-delivery feed.

The following factors cause irregularities in delivery rates: (1) "head" of fertilizer; (2) inclination of the mechanism; (3) incorrect speed; (4) incorrect delivery port openings; (5) inherent periodicity in delivery from some mechanisms; (6) compacting of fertilizer; (7) the hygroscopic and other physical properties of fertilizers.

Feed systems which meter and remove fertilizer from hoppers horizontally are superior to assisted gravity feeds, where fertilizer flows vertically. Top-delivery mechanisms are generally superior to all types of gravity feed.

Possible future developments in fertilizer distribution (including bulk spreading, aerial distribution, and the use of liquid fertilizers) are discussed. Distributors should be designed to deal specifically with fertilizers having definite physical properties. Different mechanisms may be needed to dispense materials such as free-flowing granules, dry powders and hygroscopic powdered fertilizers. Co-operative work is needed to standardize physical characteristics of fertilizers, so that in future distributors design may have a scientific basis.

16. Cooke, G. W. (& Dadd, C. V.) (1953). Fertilizer placement experiments on threshed peas. *Agriculture, Lond.*, **60**, 34.

Experiments were carried out by the National Agricultural Advisory Service to extend comparisons of placed and broadcast phosphate–potash fertilizer for threshed peas to more distant areas of the Eastern Counties.

The results of earlier Rothamsted Experiments and of the N.A.A.S. experiments were consistent. The gain from placement (over broadcasting) on the average of seventeen Rothamsted experiments was 1·9 cwt./acre of peas, and the corresponding gain in the N.A.A.S. experiments was 2·0 cwt./acre of peas.

The gains in yield from drilling PK fertilizer at the side of the seed were greater than from broadcasting twice as much fertilizer. Relatively small quantities of placed fertilizer are sufficient for maximum yields and on soils where threshed peas respond to phosphate and potash fertilizers it will pay farmers to use placement drills to apply dressings beside the seed.

17. Cooke, G. W., Jackson, M. V. & Widdowson, F. V. (1954). Placement of fertilizers for potatoes planted by machines. *J. agric. Sci.*, **44**, (In the press.)

A two-row hand-dropping potato planter was modified by adding fertilizer equipment and was used in thirty-three experiments in 1951 and 1952 to plant potatoes from flat land, and compare broadcast dressings of granulated compound fertilizer with dressings placed near to the seed.

Fertilizer placed either in one band at the side and below the level of the seed or in contact with the seed gave considerably higher yields than broadcast dressings. Broadcast fertilizer gave yields similar to those given by only

one-half to two-thirds as much placed fertilizer. On the average of all the experiments placing fertilizer gave about 1 ton/acre more potatoes than broadcasting. The advantages of placement were greatest when low rates of dressing were used.

Broadcast fertilizer was cultivated deeply into the seedbed in nineteen experiments in 1952, and gave slightly lower average yields than late dressings broadcast on the seedbed.

Fertilizer placed in bands on the soil surface immediately in front of the seed-shoes gave yields similar to those given by dressings broadcast over the seedbeds in fourteen experiments in 1951. In average planting conditions fertilizer broadcast on the seedbeds or placed in front of the seed-shoes was thrown to the middle of the ridges and concentrated above the seed.

Fertilizer placed in contact with the seed gave higher average yields than dressings in a sideband at both rates of manuring in the 1951 experiments. In 1952 contact placement was slightly superior to sideband placement at low rates of fertilizer and slightly inferior at high rates. In most experiments in each year emergence was delayed by ten to fourteen days when the heavy dressing was placed in contact with the seed. Early growth was poor, but at most centres the crops recovered later in the season and gave good yields. There is most risk of damage from contact placement on light soil, on badly prepared seedbeds and in dry years. Dressings of 10–12 cwt./acre of ordinary-strength compound fertilizers are likely to be quite safe when applied in contact with the seed. If heavier dressings are to be used, part should be applied in contact with the seed and part broadcast; such split applications were satisfactory in experiments in 1951.

Farmers planting even moderate acreages of potatoes by machines will benefit by using a suitable fertilizer attachment. Equipment is needed to place fertilizer at the side of the seed so that heavy dressings can be used to secure maximum yields without risk.

18. Cooke, G. W. & Widdowson, F. V. (1953). Placement of fertilizers for row crops. *J. agric. Sci.*, **43**, 348.

In experiments on peas, beans, carrots, kale, beetroot and spinach appropriate dressings of fertilizers placed in one band 3 inches below the soil surface and 2 inches to the side of the seed did not damage germination. Peas and beans are likely to be injured when even small dressings of soluble fertilizers are drilled in contact with or below the seed.

In sixteen experiments on peas and nineteen experiments on beans in 1949–51 broadcast fertilizer gave small increases in yield of beans and peas in dry years and larger increases in wet years. In about one-quarter of all the experiments fertilizer broadcast early and either ploughed or cultivated deeply into the soils gave significantly higher yields than late dressings worked into the seedbeds. In roughly one-third of all the experiments on each crop there were significant increases in yield from placing as compared with broadcasting fertilizer. The average extra yields produced by placing fertilizer were 1·8 cwt./acre of threshed peas, 9·3 cwt./acre of green peas, 1·0 cwt./acre of winter beans and 1·3 cwt./acre of spring beans. For spring-sown crops extra yields from placement were greater than the increases from broadcasting fertilizer. There was little advantage from splitting the fertilizer dressing, broadcasting half and placing the remainder beside the seed.

In most experiments on peas and beans, yields given by a single dressing of placed fertilizer were equal to, or greater than, the yields given by double dressings of broadcast fertilizer. When placed in the correct position quite small quantities of fertilizer are sufficient for maximum yields of such crops. There was no advantage from placing fertilizer at the side of the seed for carrots, kale or beet. Placed fertilizer gave a higher yield of spinach than broadcast fertilizer.

Placing fertilizer at the side and below the level of the seed is likely to give better yields than broadcast fertilizer for crops having short growing seasons or poorly developed roots and when broadcast nutrients are immobilized in the surface soil by drought.

19. Cooke, G. W. & Widdowson, F. V. (1953). Methods of applying fertilizer for herbage crops. *J. agric. Sci.*, **43**, 358.

Phosphate–potash fertilizer was drilled in bands 20 inches apart and 3 inches below the soil surface and compared with similar dressings broadcast

on the surface for established crops of sainfoin. On unmanured plots yields were not reduced by cutting grooves for the fertilizer bands. Broadcasting fertilizer on the surface produced consistently more sainfoin hay than dressings placed in bands. In similar experiments on permanent grass broadcast fertilizer also gave consistently more hay than bands of fertilizer placed 10 inches apart. In the absence of fertilizer small decreases in yields of grass were caused by cutting grooves. The advantages of an equal supply of nutrients to all the plants in an established sward, obtained by broadcasting fertilizers, outweighs any disadvantage from confining the application to the soil surface.

Two experiments on lucerne in 1950–51 gave similar results for broadcast and placed fertilizer in the seedbed.

In a lucerne experiment laid down in spring 1952, a "starter-dose" of superphosphate drilled directly beneath the seed gave much better early growth and higher yields of lucerne than any of the dressings of broadcast phosphate and potash.

There is no case for introducing special equipment to place fertilizer in bands below the surface of established swards. For establishing lucerne and other ley crops, where fertilizers may be applied at or before sowing, there are no advantages from using special drills to place the full dressing of fertilizer at a safe distance to the side of the seed. Where combine-drills are used for sowing herbage crops they should be modified to place a small quantity of superphosphate directly beneath the seed, and the remainder of the fertilizer should be broadcast before sowing.

20. Crowther, E. M. & Benzian, B. (1953). Nutrition problems in forest nurseries. Summary report on 1951 experiments. *For. Comm. Rep. on For. Res.*, 1951–52, 94.

Annual report on investigations reviewed in the Rothamsted Report for 1951, p. 41.

21. Crowther, E. M., Warren, R. G. & Cooke, G. W. (1953). The agricultural value of alternative phosphate fertilizers (other than silicophosphate) Part II. Field experiments. *Ministry of Supply, Permanent Records of Research and Development. Monograph* 11, 109.

The work described was initiated in 1940 by the Controller of Chemical Research and Development, Ministry of Supply, as a general investigation of phosphate fertilizers made without the use of sulphuric acid.

A large variety of phosphate fertilizers were tested against standard materials in greenhouse pot experiments, and the more promising new materials were compared in field experiments on arable crops and on grass with either superphosphate or with Bessemer basic slag.

Of several mineral phosphates Gafsa was the most successful for all crops; Florida mineral phosphate was of little value for any crop. The better mineral phosphates when applied for swedes were equivalent to superphosphate supplying from one-half to three-quarters as much phosphorus. The experiments demonstrated that mineral phosphates are satisfactory only on very acid soils (below pH 5·5); their use should be restricted generally to areas in the north and west, where swedes, turnips and grass are important crops. Mineral phosphates are of little value for potatoes.

Mixtures of superphosphate with mineral phosphate gave disappointing results, and were generally of very little more value than the mineral phosphates from which they were made.

Other experiments showed that it may not be necessary to grind mineral phosphates as fine as is customary.

Mixtures of superphosphates with low-grade basic slag, with lime and with serpentine generally gave lower yields than equivalent superphosphate. There was no evidence to justify the additional cost of preparing such basic superphosphates.

Experiments on swedes and grass with different types of basic slag confirmed that the 2 per cent citric acid test differentiates satisfactorily between the more-active and less-active basic slags.

Bessemer basic slag gave its best results for establishing reseeded grass on very acid soils. For swedes and potatoes it was less efficient than superphosphate. Triple superphosphate and ordinary superphosphate gave

similar yields of swedes and potatoes. Yields of swedes given by calcium metaphosphate were equal to those from superphosphate supplying half the quantity of phosphorus.

Where arable experiments were continued for more than one year the effects of all fertilizers in the second year were small, and there were no clear differences between the residual values of superphosphate and of the other fertilizers tested. The differences in growth of grass produced by different phosphate fertilizers became smaller when the observations were continued over several seasons.

22. Rickson, J. B. (1953). Surface properties of some calcium phosphates. *Proc. Oxford Isotopes Technique Conf.*, 1951, **1**, 411.

An account of preliminary experiments on isotopic exchange with preparations of calcium phosphates, distinguishing rapid and slow reactions.

Pedology Department

23. Bloomfield, C. (1953–54). A study of podzolization.
   (*a*) Part 1. The mobilization of iron and aluminium by Scots pine needles. *J. Soil Sci.*, **4**, 5.
   (*b*) Part 2. The mobilization of iron and aluminium by the leaves and bark of *Agathis australis* (Kauri) *J. Soil Sci.*, **4**, 17.
   (*c*) Part 3. The mobilization of iron and aluminium by the leaves and bark of *Dacrydium cupressinum* (Rimu). *J. Soil Sci.*, **5**, 39.

An account of the ability of sterile aqueous extracts of the leaf and bark material to dissolve hydrous ferric and aluminium oxides. Ferric-iron is reduced to the ferrous state, and although the extent of solution-reduction is decreased by raising the pH and by aeration, the reaction still proceeds under fully aerobic conditions at pH 7·5. Evidence is given for the complex nature of the ferrous and aluminium reaction products.

24. Bloomfield, C. (1954). Part 4. The mobilization of iron and aluminium by picked and fallen larch needles. *J. Soil Sci.*, **5**, 46.

A comparison of the properties of its picked and fallen needles. Only quantitative differences were found. The fallen needles appear to be more active in dissolving the hydrous oxides.

25. Bloomfield, C. (1953). Part 5. The mobilization of iron and aluminium by ash and aspen leaves. *J. Soil Sci.*, **5**, 50.

The ability of water extracts of fallen aspen leaves to dissolve the hydrous sesquioxides is only slightly decreased by raising the pH from *c.* 5 to over 7. This is in agreement with the frequently observed alkaline reaction of the podzolic grey-wooded soils, which are formed under a predominantly aspen cover. Extracts of ash leaves have a smaller but appreciable solution effect, despite the fact that the ash is not known to possess any podzolizing properties in the field.

26. Bloomfield, C. (1953). Sesquioxide immobilization and clay movement in podzolized soils. *Nature, Lond.*, 1953, **172**, 958.

The ferrous and aluminium reaction products of the solution of ferric and aluminium oxides are strongly sorbed on soil colloids. It is suggested that this process is responsible for the formation of the B horizon of podzolized soils.

Leaf leachates have been found to deflocculate clay suspensions, both kaolinite and montmorillonite.

27. Brown, G. (1953). The occurrence of lepidocrocite in some British soils. *J. Soil Sci.*, **4**, 220.

Lepidocrocite of pedological origin in gleyed soils of North-west England and North Wales appears to be responsible for the orange mottling which is often

found in these soils. Peroxidation of surface soils is shown to give calcium oxalate trihydrate. A method of differentiating lepidocrocite, boehmite and calcium oxalate trihydrate, all of which give a strong reflection at 6·2 Å, is given.

28. Brown, G. (1953). A semi-micro method for the preparation of soil clays for X-ray diffraction studies. *J. Soil Sci.*, **4**, 229.

A method whereby the clay from small amounts of soil can be quickly prepared for study by X-ray-diffraction methods by using Perspex centrifuge tubes to make oriented aggregates. It is pointed out that for an understanding of soil processes the soil must be studied in greater detail than the usual bulk horizon samples.

29. Brown, G. (1953). The dioctahedral analogue of vermiculite. *Clay Min. Bull.*, **2**, 64.

For summary see report.

30. Brown, G. (1954). Soil morphology and mineralogy. A qualitative study of some gleyed soils from North-west England. *J. Soil Sci.*, **5**, 145.

For summary see report.

31. Brown, G. & Smithson, F. (1953). Distribution of dickite in some British sandstones. *Nature, Lond.*, **172**, 317.

A well-crystallized mineral of the kaolin group has been found in some British sandstones, and selected samples were shown to be dickite by X-ray diffraction. The sandstones where dickite has been found are Lower Carboniferous, Caernarvonshire, Millstone Grit, Anglesey and Yorkshire and Middle Jurassic, Yorkshire. Where well-formed crystals are observed microscopically there is usually evidence of alteration of other minerals.

32. Butler, J. R. (1953). The geochemistry and mineralogy of rock weathering. (1) The Lizard area, Cornwall. *Geochim. et cosmochim. Acta*, **4**, 157.

The Cornish rocks: (i) adamellite; (ii) granodiorite-gneiss; (iii) gabbro, and (iv) tremolite-serpentine are described, together with their weathering products. Illite and kaolin are present in all the clays derived from the rocks by weathering, but chlorite and vermiculite are less widespread, and talc and montmorillonoid occur in one clay only. Both mineralogically and chemically the clays resemble each other more than do the rocks. The rôle of the minor elements in the rocks, minerals and clays is discussed.

33. Butler, J. R. (1954). Trace element distribution in some Lancashire soils. *J. Soil Sci.*, **5**, 156.

Variations in the concentration of the elements B, Be, Co, Cr, Cu, Fe, Ga, Ge, La, Li, Mn, Mo, Ni, Pb, Rb, Sn, Sr, V, Yt and Zr in profiles of Meadow or Gley soils and a Brown Earth are discussed. Mn varies erratically, Sn and Pb increased markedly from the base to the surface of the profile and all the other elements increase with depth.

34. Butler, J. R. (1953). Geochemical affinities of some coals from Svalbard. *Norsk Polarinst. Skr.*, 96.

An attempt is made to decide whether or not element distribution on ash or coal basis in a particular coal seam is sufficiently distinctive to enable it to be correlated in different localities and distinguished from another seam.

The boron contents of the coals studied were similar; in ash-poor coals boron reached 1 per cent in the ash.

35. Goldschmidt, V. M. (1954). [Book:] *Geochemistry*, edited by A. Muir (Oxford: Clarendon Press).

36. Greene-Kelly, R. (1953). Identification of montmorillonoids in clays. *J. Soil Sci.*, **4**, 253.

The difficulties which occur when identifying the members of the montmorillonoid group in clays are discussed. The lithium saturation and heating test is shown to distinguish between the dioctahedral members of the group, and its use is illustrated by several examples.

37. Greene-Kelly, R. (1953). Irreversible dehydration in montmorillonite. Part 2. *Clay Min. Bull.*, **2**, 52.

The effect of preheating to 200° C. on the montmorillonoids demonstrated that montmorillonite alone showed anomalous loss of interlamellar expansion to glycerol after heating. This loss of expanding power occurred only when montmorillonite was saturated with small cations, for example lithium and magnesium. These observations are discussed with reference to the idea of cation migration into the vacant octahedral positions of the silicate sheet.

38. Greene-Kelly, R. (1953). Interpretation of D.T.A. diagrams: the low temperature peak. *Clay Min. Bull.*, **2**, 79.

The low-temperature endothermic peak obtained during the D.T.A. of montmorillonoids often shows two maxima if the exchange cations are lithium or are divalent. In contrast, if the cations are sodium or potassium the peak appears to be simple. Experimental work is described which suggests that this difference is a natural consequence of the fact that montmorillonoids possess an expanding lattice.

39. Muir, A. (1953). Vineyard Soils in England. [In: *Vineyards in England.* Edited by E. Hyams. London: Faber & Faber Ltd.]

A discussion of the distribution of mediaeval vineyards in England in relation to soil type with comparisons of continental vine-growing areas.

40. Stephen, I. (1953). A petrographic study of a tropical black earth and grey earth from the Gold Coast. *J. Soil Sci.*, **4**, 211.

A comparative study of two profiles derived from feldspar–quartz–schist and hornblende–garnet–gneiss of the Archaean Complex near Accra, Gold Coast, has shown the influence of the parent rock in determining the character of the derived soil. The basic gneiss weathers to give a sandy clay soil characterized mineralogically by quartz–garnet sand and montmorillonitic clay. The acid schist gives a quartzose sandy soil with smaller amounts of clay comprising both kaolin and montmorillonite.

Soil Microbiology Department

41. Bromfield, S. M. (1953). Sulphate reduction in partially sterilized soil exposed to air. *J. gen. Microbiol.*, **8**, 378.

H_2S was evolved from soil treated with CCl_4 when moistened with sucrose and $(NH_4)_2SO_4$ solution and incubated aerobically. H_2S formation took place when the soil moisture was less than field capacity, and over a range of pH values from 5 to 8. The organism responsible was isolated and identified as *Bacillus megaterium*. Several strains of this organism reduced sulphate in well-aerated sterilized soil and liquid media, but not in soil or liquid incubated anaerobically.

The action of CCl_4 in fresh soil is to check or destroy certain fungi and bacteria which normally inhibit sulphate reduction by *B. megaterium*. Some of these organisms were isolated and shown to be sensitive to CCl_4 and to inhibit sulphate reduction by *B. megaterium* in sterilized soil. The isolates did not exhibit antibiotic action when grown in certain defined media.

42. Kleczkowski, J., & Kleczkowski, A. (1953). The behaviour of *Rhizobium* bacteriophages during and after exposure to ultraviolet radiation. *J. gen. Microbiol.* **8**, 135.

After inactivation by ultra-violet radiation, particles of two *Rhizobium* bacteriophages interfered temporarily with the multiplication of active particles of the homologous phage, in liquid cultures of their respective host

bacteria. Inactivated particles did not affect the number of plaques produced by active particles in bacterial cultures on agar.

No evidence was found that particles that were inactive singly became active when two or more of them infected the same bacterial cell.

The rate of inactivation approximated closely to that of a first-order reaction. Exposing infected bacteria to visible light increased the residual activities of irradiated phage preparations by amounts equivalent to decreasing the doses of ultra-violet irradiation by a constant factor. Exposing either the irradiated phage preparations or the bacterial cultures separately to visible light had no effect.

Those ultra-violet-irradiated phage particles which remained active were so altered that they became relatively unstable.

43. Kleczkowski, J. & Kleczkowski, A. (1952). Effect of specific polysaccharides from the host bacteria and of ribonuclease on the multiplication of rhizobium phages. *J. gen. Microbiol.*, **7**, 340.

Two serologically unrelated strains of nodule bacteria produced two different polysaccharides, only one of which precipitated with antiserum to its parent bacterium. Both polysaccharides interfered with the multiplication of two bacteriophages in liquid cultures of the two bacterial strains, each of which was susceptible to only one of the two bacteriophages. One polysaccharide was slightly more effective than the other in interfering with multiplication of both bacteriophages; one phage was much more susceptible than the other to the interfering action of both polysaccharides. Crystallized pancreatic ribonuclease interfered with multiplication of bacteriophages much more strongly than did the polysaccharides. Neither the polysaccharides nor ribonuclease destroyed the phage particles.

44. Kleczkowski, J. & Kleczkowski, A. (1954). A study of the mechanism of inhibition of bacteriophage multiplication by chymotrypsin. *J. gen. Microbiol.*, **10**. (In the press.)

When 0·01 per cent chymotrypsin is added to mixtures of *Rhizobium* bacteriophage and bacteria in liquid cultures, the multiplication of phage is prevented, and the phage gradually becomes inactive. The rate and extent to which phage and bacteria combine are unaffected by the chymotrypsin, whose effect seems directed against an early stage in the interaction between the two. This stage persists, on an average, for less than 1 minute from the moment of combination. A phage particle combined with a bacterium becomes inactive, and the bacterium is thus protected against lysis and remains able to multiply. Chymotrypsin does not interfere with combination between phage and bacteria killed by ultra-violet radiation; the combination leads to loss of phage activity, irrespective of the presence of chymotrypsin. The multiplication of the phage is unaffected by previous incubation of either the phage or of the host bacteria separately with 0·01 per cent chymotrypsin.

Chymotrypsin has no effect on phage–host interaction in an agar medium.

45. Meiklejohn, J. (1953). Microbiological aspects of soil nitrification, with special reference to the Kawanda Nitrate Experiment. *E. Afr. agric. J.*, **19**, 54.

In the nitrate accumulation experiment at Kawanda, Uganda, it has been observed that more nitrate accumulated in fallow soil exposed to the sun than in fallow soil shaded from the sun or covered with a grass mulch. Cultures of autotrophic nitrifying bacteria were obtained from the surface soil of fallow plots treated in all three ways; but, contrary to expectation, the least-vigorous cultures were obtained from the exposed soil, where the most nitrate had accumulated. The nitrifying bacteria obtained from the exposed fallow were not thermophilic; and all the nitrifying cultures grew better in a neutral medium than in an acid one, although the pH of the surface soil was 4·6–5·0.

46. Meiklejohn, J. (1953). The effect of bush burning on the microflora of some Kenya soils. *6th Int. Congr. Microbiol.*, Rome, Sept.

The burning of shrubs, undergrowth and grass, in order to clear the land for planting, is a very widespread farming practice in the tropics, but scientifically it has been very little studied. In the present work the microflora of the

surface soil from three sites at Muguga, Kenya, was studied before and after burning. Two of the soils had carried Black Wattle (*Acacia decurrens*) and a light undergrowth of small shrubs; the third was an abandoned African cultivation site, which had carried rough grass for two years.

In all three sites burning caused an immediate reduction in the numbers in the top inch of soil of microfungi, actinomycetes and bacteria. There was also evidence that nitrifying bacteria, and both aerobic and unaerobic free-living nitrogen-fixers, were killed by burning the grass and shrubs above the soil.

47. Meiklejohn, J. (1953). Life in the Soil. *Proc. Nairobi sci. and philos. Soc.*

48. Read, M. P. (1953). The establishment of serologically identifiable strains of *Rhizobium trifolii* in field soils in competition with the native microflora. *J. gen. Microbiol.*, **9**, 1.

Field trials were made at thirteen centres in varied localities to test whether a strain of clover *Rhizobium* used as a seed inoculum in the field could establish itself in the crop in competition with the native strains already present in the soil. Each experiment comprised four sets of quadruplicate plots, one uninoculated and the other three each sown with seed inoculated with a different strain of *Rhizobium*.

The difficulty in identifying a strain re-isolated from a nodule was met by using as inocula strains whose antigenic composition made them readily identifiable by agglutination tests. From each plot twenty-five nodules were selected, and isolates from these tested against selected antisera. This method of identification enabled the percentage of nodules produced by each inoculant strain to be ascertained. Strains differed in their ability to establish themselves in the field; a suitable strain gave rise to 50 per cent or more of the nodules. In sand culture competition between pairs of inoculant strains was not related to their ability to establish themselves in the field, but each strain whose establishment was superior also showed competitive dominance on at least one date of sampling.

49. Skinner, F. A. (1953). Inhibition of *Fusarium culmorum* by *Streptomyces albidoflavus*. *Nature, Lond.*, **172**, 1191.

Streptomyces albidoflavus arrested the growth of *Fusarium culmorum* by antibiotic secretions in agar media containing 10 g. glucose per litre. On media with lower glucose contents the fungus continued to grow towards the actinomycete, but there was evidence that traces of antibiotic material were formed by the latter. Both organisms grew on a variety of natural organic materials supported on buffered agar, but fungal growth was arrested at a distance from the actinomycete only when dried grass was used as source of nutrients. Filtrates of liquid cultures of the actinomycete contained a substance inhibitory to growth of *F. culmorum*, but this could be inactivated by additions of bentonite, other clays, whole soils and organic matter. In sand moistened with liquid medium containing glucose the actinomycete limited growth of the fungus by antibiotic action, by a direct attack on the fungal mycelium and by competition for the available nutrients. The effectiveness of all these antagonistic mechanisms was reduced when the glucose concentration was lowered. Antibiotic and direct-attack phenomena could not be detected when bentonite was added to the cultures. Neither antibiotic attack nor direct attack on the fungus could be demonstrated in sterile soil, though there was evidence of competition between the organisms for nutrients or space.

50. Thornton, H. G. & Skinner, F. A. (1953). The interaction of actinomycetes with other micro-organisms in soil. *6th Int. Congr. Microbiol. Symposium on Actinomycetales*, 174.

The antagonism displayed by many soil actinomycetes against other micro-organisms, particularly bacteria and fungi, in artificial culture and in soil, is discussed in this review paper. Particular attention is paid to the complexity of the interactions between these micro-organisms in soil and to the possible importance of antibiotic production, competition for nutrients and the presence of soil colloids.

51. Walker, N. (1954). Preliminary observations on the decomposition of chlorophenols in soil. *Plant & Soil*, **5**. (In the press.)

It has been shown that *o*-chlorophenol is much less persistent in soil than *p*-chlorophenol or 2 : 4-dichlorophenol and that the decomposition of *o*-chlorophenol in soil is a biological process. There is evidence that *p*-chlorophenoxyacetic acid is subject to biological decomposition in soil.

52. Walker, N. & Wiltshire, G. H. (1953). The decomposition of naphthalene and α-chloro- and α-bromo-naphthalenes by soil bacteria. *6th Int. Congr. Microbiol.*, Riassunti delle Communicazioni, **1**, 175.

A strain of a naphthalene-utilizing bacterium will grow with either α-chloronaphthalene or α-bromonaphthalene as carbon source. 3-Chorosalicylic acid and a chloronaphthalene diol have been isolated from cultures grown on α-chloronaphthalene. Similarly, in bromonaphthalene cultures, a diol has been detected, and an acid which is probably a bromosalicylic acid has been isolated.

Botany Department

53. Humphries, E. C. (1954). Mineral components and ash analysis. (*Modern methods of plant analysis*. Edited by K. Paech and M. V. Tracey. Section III. Heidelberg : Springer-Verlag. (In the press.)

54. Thorne, G. N. (1954). Absorption of nitrogen, phosphorus and potassium from nutrient sprays by leaves. *J. exp. Bot.*, **5**. (In the press.)

Barley, Brussels-sprout, French-bean, tomato and sugar-beet plants grown in soil in pots and sprayed, usually daily, for several weeks, with nutrient solutions containing nitrogen, phosphorus, potassium and a spreader, with precautions to prevent the spray solution falling on the soil, had higher nutrient contents and dry weights than control plants sprayed with water and spreader only. Increase in nutrient content occurred with high or low levels of nutrient supply to the roots, and was approximately proportional to the concentration of spray and to the frequency of spraying.

The nitrogen content of sugar-beet plants was increased equally by spraying with solutions supplying ammonium sulphate, calcium nitrate or urea in equivalent concentrations.

Nutrient uptake from solutions sprayed on leaves influenced uptake by the roots, so that the additional amounts of nutrient contained in sprayed plants may be greater or smaller than the amount absorbed from the spray by the leaves.

55. Thurston, J. M. (1954). The biological approach to the problem of wild oats control. *Proc. Brit. Weed Control Conf.*, 1953. (In the press.)

Present knowledge of the biology of wild oats, based on experiments and observations in Great Britain and abroad, is summarized, and its relation to control measures is discussed.

56. Warington, K. (1950). Work on trace elements in England, Scotland and Ireland. *Proc. Soil. Sci. Soc. Fl.*, **10**, 181.

A review of investigations carried out in Great Britain from 1896 to 1950, contributed to a symposium on trace elements.

57. Warington, K. (1954). The influence of iron supply on toxic effects of manganese, molybdenum and vanadium on soybean, peas and flax. *Ann. appl. Biol.*, **41**, 1.

Reduction of the standard iron supply in the nutrient solution accentuated the toxicity of 2·5 or 5 p.p.m. vanadium to soybean and flax, but injury from

high manganese (10 p.p.m.), molybdenum (40 p.p.m.) or vanadium (2·5 p.p.m.) was counteracted by increasing the iron to 20 or 30 p.p.m. Fe. The range of concentrations tested varied with the crop, the lowest levels being 1·25, 2·5 or 5·0 p.p.m. Fe for peas, soybean and flax respectively. Ferric citrate was the source of iron. Varying the iron supply had little effect on growth when the concentration of the three elements was low. Where increased iron had reduced the chlorosis caused by high manganese or vanadium, it also reduced the amount of these elements in the shoot, but the molybdenum content was lowered by high iron only when given in non-toxic concentration (0·1 p.p.m. Mo) combined with excess manganese.

The iron content of the shoot was scarcely affected by variation in the amount of iron supplied, but was generally reduced by high concentrations of manganese, molybdenum or vanadium.

58. Watson, D. J. (1953). Research on virus diseases of sugar beet. *Brit. Sug. Beet Rev.*, **22**, 27.

59. Watson, D. J. (1954). Measurement of photosynthesis in field conditions, *and* The physiological limitations of crop yield and the possibilities of increasing it. *Landbouwk. Tijdschr., 's-Grav.*, 66. (In the press.)

Text of two lectures on the results of growth-analysis studied on field crops given in a course on photosynthesis at the University of Wageningen.

Biochemistry Department

General Papers

60. Pirie, N. W. (1952). Large scale production of edible protein from fresh leaves. *Rep. Rothamsted exp. Sta.*, 1952, 173.

61. Pirie, N. W. (1953). The efficient use of sunlight for food production. *Chem. & Ind.*, 443.

62. Pirie, N. W. (1953). Research for Plenty. No. 8, New foods for a crowded world. *Agriculture, Lond.*, **60**, 116; and reprint by Bles.

63. Pirie, N. W. (1953). Ideas and assumptions about the origin of Life. *Discovery*, **14**, 238; and in the *Literary Guide*, January 1954.

64. Pirie, N. W. (1953). Cellulase as a subject for speculation and commercial enterprise. *Biochem. Soc. Symp.*, **11**, 51.

65. Pirie, N. W. (1953). Some host components that affect viruses during isolation. In symposium " Interaction of viruses and cells," Rome, 1953.

66. Tracey, M. V. (1953). Cellulases. *Biochem. Soc. Symp.*, **11**, 49.

A survey of the present state of knowledge of cellulases. Emphasis is laid on the importance of the insoluble nature of cellulose in interpreting the action and hydrolytic properties of the enzymes. Reference is also made to similar properties of chitinases.

Research Papers

67. Holden, M. (1953). A comparison of the applicability to plant extracts of three methods of determining deoxyribonucleic acid. *Analyst*, **78**, 542.

The diphenylamine method (Dische, 1930) and a modification of the tryptophan–perchloric acid method of Cohen (1944) have been found to be satisfactory for determining deoxyribonucleic acid in extracts from plant tissues. The cysteine–sulphuric acid method (Stumpf, 1947) has given erratic results. A number of substances, some of which are likely to be present in plant extracts, have been tested under the conditions of the three methods.

68. Kenten, R. H. (1953). The oxidation of phenylacetaldehyde by plant saps. *Biochem. J.*, **55**, 350.

1. Many plant saps oxidize phenylacetaldehyde. The system in pea-seedling sap consists of a thermolabile factor which appears to be a peroxidase and a thermostable factor which can be partially replaced by manganous ions. A system with similar properties to that in the pea-seedling sap can be constructed using horseradish peroxidase preparations and manganous ions.

2. The oxidation when catalysed by either pea-seedling sap or horseradish peroxidase and manganous ions proceeds with the formation of benzaldehyde and formic acid.

69. Kenten, R. H. & Mann, P. J. G. (1953). The oxidation of certain dicarboxylic acids by peroxidase systems in the presence of manganese. *Biochem. J.*, **53**, 498.

1. The oxidation of oxalate, oxaloacetate, ketomalonate and dihydroxytartrate by oxygen is catalysed by peroxidase systems in the presence of Mn^{2+}.

2. It is suggested that these oxidations and that of dihydroxymaleate in presence of peroxidase systems and Mn^{2+} involves the oxidation of Mn^{2+}.

70. Pirie, N. W. (1954). The fission of tobacco mosaic virus and some other nucleoproteins by strontium nitrate. *Biochem. J.*, **56**, 83.

Tobacco mosaic virus is split at room temperature into denatured protein and free nucleic acid by solutions of strontium nitrate more concentrated than 1*M*.

Other nucleoproteins are less easily split in this way, and other related salts are not so efficient as strontium nitrate.

Nucleic acid is decomposed by more intense treatment.

71. Smithies, W. R. (1953). The lysing action of enzymes on a sample of mycelium of *Penicillium griseofulvum* Dierckx. *Biochem. J.*, **55**, 346.

1. Air-dried mycelium of *Penicillium griseofulvum* was subjected to autolysis. The suspended matter in the final product contained 16 per cent of the original protein, 6 per cent of the carbohydrate and 50 per cent of the chitin. The solution contained dispersed protein and carbohydrate, but no α-amino acids or reducing sugar.

2. Air-dried mycelium after two to three years' storage was autolysed. The suspended material contained 39 per cent of the original protein, 7 per cent of the carbohydrate and 70 per cent of the chitin. The solution contained amino acids reducing sugar and *N*-acetylglucosamine.

3. The protease of the mycelium is stable to storage. Much polysaccharide-splitting and chitinase activity is lost on drying, but some of the residual activity remains after three years. Such stored mycelium contains a very weak glucose oxidase, but no α-amino-acid oxidase, which was presumably very active in the fresh dry mycelium.

4. Little change takes place in the composition of the mycelium on storage, except for a slight hydrolysis or protein.

5. 10–15 per cent of the mycelium protein resists digestion with proteases; 10–25 per cent of the carbohydrate and about 10 per cent of the chitin resists digestion with juice from the alimentary tract of snails.

72. Walker, N. & Wiltshire, H. (1953). The decomposition of naphthalene and α-chloro- and α-bromo-naphthalenes by soil bacteria. *Proc. 6th Int. Congr. Microbiol.*, **1**, 175.

For summary see No. 52.

73. Wiltshire, G. H. (1953). The optical form of glutamic acid in tumours. *Brit. J. Cancer*, **7**, 137.

One normal tissue and four tumours were analysed for isomers of glutamic acid by methods applied to purified proteins. The percentage of D-glutamic acid found was in all cases very small, and not more than would be formed by the inversion of the L-isomer during hydrolysis.

74. WILTSHIRE, G. H. (1953). The estimation of D- and L-glutamic acid in proteins. *Biochem. J.*, **55**, 46.

Total glutamic acid was estimated by amino-nitrogen analysis after separation from other amino acids on buffered ion-exchange columns. The carbon dioxide released by enzymic decarboxylation of the L-isomer was measured manometrically. Five per cent of L-isomer was produced from L-glutamic acid under the conditions of acid hydrolysis and subsequent analysis. D-Glutamic acid in excess of that estimated to be formed by inversion was found in hydrolysates of proteins which had been treated with dilute alkali, and in the cells of *Lactobacillus casei*, but not in four purified plant and animal proteins or in tobacco mosaic virus protein.

75. WILTSHIRE, G. H. (1953). The oxidation of tryptophan in pea-seedling tissues and extracts. *Biochem. J.*, **55**, 408.

The oxidation of tryptophan in tissue slices and extracts from pea seedlings was accelerated by addition of certain amines, which are concurrently oxidized with production of hydrogen peroxide. In the extract a compound having some of the properties of 3-hydroxykynurenine was formed. The reaction of one molecule of tryptophan with two molecules of hydrogen peroxide was catalysed by peroxidase, both in purified extracts and in model systems employing peroxide-donating enzymes and purified peroxidases.

76. (BOYLAND, E.) & WILTSHIRE, G. H. (1953). Metabolism of polycyclic compounds. The metabolism of naphthalene, 1-naphthol and 1 : 2-dihydroxy-1 : 1-dihydronaphthalene by animals. *Biochem. J.*, **53**, 636.

Repeated doses of naphthalene to male rats resulted in an increased proportion excreted as naphthalene diol and a decreased proportion excreted as glucuronide.

Plant Pathology Department

GENERAL PAPERS

77. BAWDEN, F. C. (1953). The control of plant diseases. In *Research for Plenty*. London : Geoffrey Bles. p. 35.

78. BAWDEN, F. C. (1953). The initiation and development of virus infection. *Symposium, Istituto Superiore di Sanita, Rome, 6th Int. Congr. Microbiol.*

79. BROADBENT, L. (1952). The epidemiology of aphid-borne virus diseases. *Trans. 9th Int. Congr. Ent.* **1**, 619.

80. BROADBENT, L. (1953). Aphid control to combat lettuce mosaic. *Grower*, **40**, 774.

81. BROADBENT, L. (1953). Aphids and virus diseases in potato crops. *Biol. Rev.*, **28**, 350.

82. GLYNNE, MARY D. (1953). Wheat yield and soil-borne diseases. *Ann. appl. Biol.*, **40**, 221.

83. GLYNNE, MARY D. (1953). Lower seed rates to save lodging. *Times agric. Rev.*, Autumn 1953.

84. GREGORY, P. H. (1953). The fungi of Hertfordshire : Supplement I. *Trans. Herts. Nat. Hist. Soc.*, **24**, 38.

85. HULL, R. (1953). Assessment of disease incidence in the sugar-beet crop. *Ann. appl. Biol.*, **40**, 603.

86. HULL, R. (1953). Assessments of losses in sugar beet due to Virus Yellows in Great Britain 1942–52. *Plant Pathology*, **2**, 39.

87. Salt, G. A. (1953). A field experiment on wheat infected with eyespot. *Ann. appl. Biol.*, **40**, 224.

Research Papers

88. Bawden, F. C., Hamlyn, Brenda M. G. & Watson, Marion A. (1954). The distribution of viruses in different leaf tissues and its influence on virus-transmission by aphids. *Ann. appl. Biol.*, **41**.

Exposing both surfaces of leaves systemically infected with cabbage black ring spot virus (CBRSV) or with henbane mosaic virus to ultra-violet radiation decreases the infectivity of expressed sap to about one-fifth. As irradiation probably inactivates virus only in the epidermis, which occupies about one-quarter the volume of the leaves, these viruses seem to occur at much higher concentrations in sap from the epidermis than in sap from other cells. By contrast, tobacco mosaic virus seems not to occur predominantly in the epidermis.

CBRSV and henbane mosaic virus are normally transmitted most frequently by previously fasted aphids that feed for only short periods on infected leaves, but aphids treated like this transmit rarely from leaves that have been exposed to ultra-violet. Irradiation has relatively little effect on the proportion of aphids that transmit after long infection feedings. Fasting seems to increase transmission by increasing the probability that aphids will imbibe sap from the epidermis of leaves they newly colonize. With longer periods on infected leaves, the ability of fasted aphids to transmit probably decreases, because they then feed from deeper cells and their stylets contain sap with less virus. Only virus contained in the stylets seems to be transmitted, not virus taken into the stomach. About half the transmissions of henbane mosaic virus by aphids that have colonized tobacco leaves for hours may be caused by insects that temporarily cease feeding on the phloem and newly penetrate the epidermis.

Irradiating infected leaves affected the transmission of sugar-beet mosaic virus in the same way as that of henbane mosaic virus, but had little effect on the transmission of beet yellows virus, whose vectors become more likely to transmit the longer they feed on infected plants.

89. Bawden, F. C. & Kassanis, B. (1954). Some effects of thiouracil on virus-infected plants. *J. gen. Microbiol.*, **10**, 160.

Submerging leaves in water soon after they are inoculated with viruses can prevent infection, and for studying factors that affect the rate of virus multiplication leaves should not be placed in solutions until a day after noculation.

The rate at which viruses multiply in tobacco leaves is decreased by spraying with solutions of thiouracil, but less so than by floating leaves in the solutions. The physiological state of floated leaves affects the extent to which thiouracil impedes virus multiplication; least virus is produced in the presence of thiouracil when the condition of leaves otherwise most favours virus formation. Multiplication of virus can be checked at any time by thiouracil, but is most affected when leaves contain little virus; multiplication is resumed when thiouracil is removed. Thiouracil impedes the multiplication in tobacco of all viruses tested, but not of a tobacco necrosis virus in French bean or broad-bean mottle virus in *Vicia faba*.

When mixed with inocula, thiouracil can prevent infection from occurring, both in tobacco and French bean. It also affects the growth and appearance of both plants. These effects, unlike the impedance of virus multiplication in tobacco, are not counteracted by an excess of uracil. Tobacco leaves in which tobacco mosaic virus is multiplying develop necrotic spots and rings when treated with thiouracil, and local lesions can be made evident by spraying inoculated leaves. Necrotic lesions also occur on *V. faba* infected with broad-bean mottle virus and treated with thiouracil.

90. Broadbent, L. (1954). The different distribution of two brassica viruses in the plant and its influence on spread in the field. *Ann. appl. Biol.*, **41**.

Previous knowledge did not explain the greater prevalence of cauliflower mosaic than of cabbage black ring spot virus. Both viruses are spread by

Myzus persicae and *Brevicoryne brassicae*, and both are transmitted equally readily from infected seedlings. Cabbage black ring spot virus has the wider host range.

Part of the difference between the rate at which the two viruses spread can be accounted for by the different manner in which they are distributed in old infected plants. Cauliflower mosaic virus occurs in high concentration in young leaves of old plants, whereas cabbage black ring spot virus occurs in quantity only in the older leaves, where it is localized in parts that show symptoms. After flying, most aphids alight on the upper parts of plants, where they are less likely to acquire cabbage black ring spot virus than cauliflower mosaic virus. In cabbage the old leaves are more favourably placed to catch alighting aphids than in cauliflower, and cabbage crops are often extensively infected with cabbage black ring spot virus.

91. Broadbent, L. & Tinsley, T. W. (1953). Symptoms of cauliflower mosaic and cabbage black ring spot in cauliflower. *Plant Pathology*, **2**, 88.

The succession of symptoms in plants infected with cauliflower mosaic and cabbage black ring spot viruses is described, together with variations caused by changes of temperature, light intensity and manuring.

92. (Brodie, Harold J.) & Gregory, P. H. (1953). The action of wind in the dispersal of spores from cup-shaped plant structures. *Canad. J. Bot.*, **31**, 402.

When smoke flowed over conical glass funnels in a wind tunnel, two eddy systems were observed. The first took the form of twin vortices, one on either side of the median line in the funnel. Each vortex was smallest at the narrowest part of the funnel and widened upwards. The second system was a single permanent elliptical eddy near the funnel mouth. The upper side of this eddy moved with the wind, the lower against it.

Observation of *Lycopodium* spores in glass vessels of various sizes and shapes subjected to winds ranging from 0·6 to 7·1 metres per second, showed that spores are blown from funnel- or egg-shaped vessels more readily than from rectangular vessels or horizontal glass slides. *Lycopodium* spores were not visibly dispersed from a funnel with mouth 4 cm. diameter at wind speeds below 3 metres/second.

Soredia of the lichen *Cladonia* were blown out of their funnel-shaped podetia by winds of 1·5–2 metres/second (3·3–5·3 m.p.h.) although no soredia were blown from a horizontal glass slide at the same wind speeds.

The two eddy systems created by wind blowing over funnel-shaped plant structures are thought to be adequate to remove spores and bodies of comparable size. The twin vortices suck spores from the bottom of the funnel, and the rotation of the upper elliptical eddy raises the spores along the upwind wall of the funnel and ejects them into the wind above.

This kind of dispersal could occur in a variety of plants, including Discomycetes and wind-pollinated plants.

93. (Croxall, H. E., Gwynne, D. C.) & Broadbent, L. (1953). Turnip Yellow Mosaic in broccoli. *Plant Pathology*, **2**, 122.

Turnip yellow mosaic virus infected many winter cauliflower and other brassica crops in a small area on the coast of North-east England during 1952–53. This outbreak, the first to be recorded in broccoli in Britain, was probably caused by virus spread by flea-beetles, which were exceptionally numerous in these years. Plants infected in autumn were either killed by frost or failed to produce marketable curds.

94. (Gendron, Yves) & Kassanis, B. (1954). The importance of the host species in determining the action of virus-inhibitors. *Ann. appl. Biol.*, **41**.

The saps of some plant species from which viruses are difficult to transmit to other species by sap-inoculation contain substances that inhibit infection. The extent to which they inhibit infection depends on the species of plants inoculated and not on the identity of the virus. The inhibitors do not prevent infection of species that contain them.

Infection of cucumber was less affected than any of the other species by all the inhibitors tested.

95. Gregory, P. H., Hirst, J. M. & Last, F. T. (1953). Concentrations of basidiospores of the dry rot fungus (*Merulius lacrymans*) in the air of buildings. *Acta allerg., Kbh.*, **6**, 168.

The spore content of the air in two buildings affected by *Merulius lacrymans* was estimated during autumn 1952, using power-operated suction traps. In a bomb-damaged house in London concentrations ranged from 79,500 spores/cu. metre in a cellar with active fruit-bodies to 16,000/cu. metre on a first-floor room without fruit bodies. In a country house concentrations ranged from 360,000 spores/cu. metre in a cellar to 1,630 spores/cu. metre in a first-floor corridor, both with active fruit-bodies. The undisturbed air in an old unaffected cottage in Harpenden contained no spores of *Merulius lacrymans* and less than 10 spores/cu. metre of any kind.

96. Gregory, P. H. & Stedman, O. J. (1953). Deposition of airborne *Lycopodium* spores on plane surfaces. *Ann. appl. Biol.*, **40**, 651.

The deposition of *Lycopodium* spores on sticky surface traps, including vertical and horizontal microscope slides and Petri dishes as used in routine aerobiological survey, was studied in a small wind tunnel at wind speeds from approximately 0·5–9·5 metres/second.

Deposition results from several processes acting singly or in combination. The pattern of deposit on a microscope slide orientated at angles varying from 0 to 90° to the wind, with gravity either positive, neutral or negative, indicates that, except on a surface parallel to the wind at the lowest wind speed, sedimentation under gravity plays a minor part in deposition on plane surfaces. As the wind speed is increased the deposit is decreased because of " edge shadow ". At the highest wind speed the deposit is as large on the lower as on the upper surface on the horizontal slide, which suggests deposition by turbulence. Deposition by impaction against a vertical strip increases with wind speed and efficiencies observed are lower than for cylinders of the same diameter. The deposit on slides inclined at angles of 45° or less to the wind direction is increased by impaction of an " edge drift ". The interaction of these various deposition processes on mean deposition at different angles and wind speeds gives a series of curves with a maximum at 90° and 9·5 metres/second and with minima at 0°, 90° and 180° at wind speeds lower than 9·5 metres/second. At these lower wind speeds there are two maxima in the range 20–70° and 135°–150° respectively.

Deposits on Petri dishes show rim effects differing at different wind speeds. These can be eliminated by sinking the dish below a flat surface.

Blow-off from non-sticky surfaces is least at about 45°, and greatest at 0°.

Spore concentration in air is difficult to estimate from the deposits on plane-surface traps, because horizontal traps under-record at medium wind speeds, and because vertical traps are very sensitive to changes in wind speed. Power-operated suction traps are to be preferred when data on spore concentrations are required.

97. Hamlyn, Brenda M. G. (1953). Quantitative studies on the transmission of cabbage black ring spot virus by *Myzus persicae* (Sulz.). *Ann. appl. Biol.*, **40**, 393.

Factors affecting the transmission of cabbage black ring spot virus by *Myzus persicae* (Sulz.) were studied quantitatively using the local lesions produced on tobacco leaves. Aphids prevented from feeding for 15 minutes or more, before feeding for a few minutes on an infected plant, caused more infections than unfasted aphids. Fasted aphids acquired virus from infected plants in feeding times as short as 10 seconds, and infected healthy plants in test-feeding times of 5 seconds. Increasing test-feeding times to 30 minutes increased the numbers of infections. Increasing infection-feeding times from ten seconds to 5 minutes had little effect, but increasing to more than than 5 minutes greatly reduced the number of transmissions. This reduction was partly offset if the aphids were prevented from feeding continuously while on the infected plants. With undisturbed infection-feeding periods of 15 minutes or longer, previously fasted aphids caused no more infections than unfasted aphids.

Infective aphids lost their ability to produce lesions more rapidly when feeding than when fasting.

Winged and wingless aphids were equally efficient vectors.

98. Hirst, J. M. (1953). Changes in atmospheric spore content: Diurnal periodicity and the effects of weather. *Trans. Brit. mycol. Soc.*, **36**, 375.

The use of a power-operated suction trap, in which spores are impacted on the sticky surface of a slowly moving slide, made it possible to estimate accurately the concentration of different kinds of spore in the air at any given time. The catches often consisted predominantly of small hyaline spores, types rarely caught by other kinds of trap. Changes in the types of spore caught at different times of day showed that some species have a well-defined diurnal periodicity; the catches also reflect changes in weather.

In dry weather, pollen grains and spores of such fungi as *Cladosporium*, *Erysiphe*, *Alternaria*, smuts and rusts, are the main components of the air spora; they are most abundant in the afternoon and least in the early morning. *Phytophthora infestans* and *Polythrincium trifolii* also occur, but are earlier and reach their maximum concentration before noon. Prolonged rain removes most of these spores, and for a time there are few in the air. Within a few hours of the start of rain, the typical dry-air spora is replaced by hyaline spores; few of these can be identified, but they include splash-dispersed types, ascospores and basidiospores. Except after rain, this damp-air spora occurs in quantity only at night when dew is formed, and the greatest concentration is reached between midnight and dawn.

Basidiospores were at times the dominant type of spore. Hyaline forms, often mainly *Sporobolomyces* sp., rapidly reached large numbers in the early hours of the morning, particularly when there was heavy dew, and then disappeared almost completely. Coloured basidiospores mainly from the Agaricales were also commonest at night, but their occurrence depended less on weather than the hyaline forms, and their diurnal periodicity was less pronounced.

99. Hirst, J. M., Long, I. F. & Penman, H. L. (1954). Micro-meteorology in the potato crop. *Quart. J. R. met. Soc.*

Two main causes of reduced potato yields are virus diseases and blight. Some of the virus diseases are aphid-transmitted. Measurements of temperature, humidity and wind in potato crops showed that weather among the plants often favoured aphid flight when weather outside did not.

During the summers of 1952 and 1953 wet- and dry-bulb temperatures were continuously recorded at six heights in and above a potato crop (10–320 cm.). For part of the period a dew balance also recorded the changes in weight of a potato shoot as dew condensed and later re-evaporated. These changes were in phase with vapour-pressure gradients in the air, which was saturated, or very nearly so, at all levels up to 160 cm. during the period the leaves were wet.

100. Kassanis, B. (1953). Some effects of sucrose and phosphorus in increasing the multiplication of tobacco mosaic virus in detached tobacco leaves. *J. gen. Microbiol.*, **9**, 467.

Tobacco mosaic virus reached higher concentrations when inoculated tobacco leaves were placed in a solution containing 10 g./l. sucrose and 0·2 g./l. calcium phosphate than when in water. Detached leaves in water usually produced more virus than leaves left on the plants. Other sugars and phosphates also increased virus production. Sugar and calcium phosphate sometimes separately increases the concentration of the virus, but the response was usually greatest to both together. The increase varied with the nutritional state of the plants from which the leaves came and with some other environmental conditions. Virus concentration, and the effect of sucrose and calcium phosphate in increasing it, was greater when leaves were in the light than in the dark. Conditions which increased virus concentration also increased the total carbohydrates of the leaves.

101. Kassanis, B. (1954). Tobacco necrosis viruses affecting tulips. *Plant Pathology*. (In the press.)

Different methods of inoculation were tried, but all failed to reproduce the lethal necrotic symptoms usually seen when forced tulips are naturally infected. The only result was some necrotic spotting of the leaves, varying in severity with different varieties of tulips. Observations made in natural outbreaks of the disease in forced tulips suggest that the infection occurred the year before.

102. Kleczkowski, A. (1954). Stability of chymotrypsin and tobacco mosaic virus decreased by ultra-violet radiation. *Biochem. J.*, **56**, 345.

When proteins with specific activities are exposed to ultra-violet radiation, the specific activity is not necessarily lost by the first alteration produced. Chymotrypsin molecules can be altered by the radiation so that their stability at temperatures around 37° at pH 7 is decreased, although they are still proteolytically active. The increased rate at which tobacco mosaic virus is denatured on heating after irradiation results from a series of changes succeeding those associated with the loss of infectivity.

103. (Nutman, F. J.) & Roberts, F. M. (1953). Two new species of fungi on clove trees in the Zanzibar Protectorate. *Trans. Brit. mycol. Soc.*, **36**, 229.

Two species of fungi pathogenic to clove (*Eugenia aromatica*) are described.

Valsa eugeniae sp. nov. always occurs in clove-trees which have died of the sudden-death disease, and it also causes die-back.

Cryptosporella eugeniae Nutman & Roberts is a severe wound parasite that attacks clove-trees of all ages and often kills young trees.

104. Tinsley, T. W. (1953). The effects of varying the water supply of plants on their susceptibility to infection with viruses. *Ann. appl. Biol.*, **40**, 750.

Increasing the amount of water supplied to plants before they were inoculated with viruses greatly increased their susceptibility to infection; plants that received unlimited water produced ten or more times as many local lesions as plants that received only enough to prevent wilting. Susceptibility was increased throughout the year, but the full response occurred in two weeks in winter and four weeks in summer. Plants that received unlimited water for the two weeks immediately preceding inoculation were no more susceptible than those that received it during the previous two weeks, although the external appearance of the plants differed at the time of inoculation. Varying water supply after inoculation did not affect the numbers of lesions.

The differences in susceptibility to infection produced by differential watering were decreased, but not abolished, by growing plants under shade or by incorporating a diatomaceous earth in the inoculum.

Increasing water produced plants with larger and more succulent leaves; the cuticular layer was thinner, and the palisade tissue was less regularly arranged than in the plants kept dry. The increased susceptibility caused by abundant water may be partly due to these structural differences, which allow the leaf to be damaged more easily when inoculated.

105. Watson, Marion A. & Nixon, H. L. (1953). Studies on the feeding of *Myzus persicae* (Sulz.) on radioactive plants. *Ann. appl. Biol.*, **40**, 537.

Adult apterae of fasted *Myzus persicae* (Sulz.) were fed on leaves containing radioactive phosphorus. The weight of sap imbibed by the aphids after various feeding times was estimated by relating their radioactivity to the activity per unit weight of the leaf on which they fed. The calculations were made on the assumption that ^{32}P is uniformly distributed in the leaf.

The mean rates of uptake were about 10 μg. of sap for the first hour of feeding; 40 μg./hour between 1 and 4 hours feeding, and 17 μg./hour between 6 and 24 hours feeding. The decrease in apparent rate of uptake with the longer feeding times is attributed to loss of ^{32}P in nymphs born during the feeding period.

When aphids were fed on seedlings raised in water-culture solution containing ^{32}P, no activity was detected after 5 minutes' feeding and only a trace after 15 minutes, but when the isotope was introduced by immersing the leaves for several days in the culture solution, aphids fed for 5 minutes were detectably active.

The increase in rate of uptake after 1 hour of feeding indicates that aphids do not start to feed normally until they reach the phloem, but the activity after short feeding times suggests that previously fasted aphids do feed on other tissues, possibly the epidermis.

Nematology Department

General Papers

106. Peters, B. G. (1953). Control of plant nematodes. *Rep. Progr. appl. Chem.*, **37**, 276.

107. Peters, B. G. (1953). The golden nematode in Britain. *Amer. Potato J.*, **30**, 226.

Research Papers

108. Brown, E. B. & Franklin, M. T. (1953). Experiments on control of eelworm in black currants. *Plant Pathology*, **2**, 101.

Spraying with 0·025 per cent parathion in early summer reduced the numbers of live eelworms in the buds of black-currant bushes, as did also severe pruning. A later spraying appeared to be without effect. The treated bushes showed less damage than the untreated in the following year. Appreciable numbers of black-currant eelworms were found in the weeds surrounding infested bushes.

109. Doncaster, C. C. (1953). A study of host-parasite relationships. The potato-root eelworm, *Heterodera rostochiensis* in black nightshade, *Solanum nigrum* and tomato. *J. Helminth.*, **27**, 1.

It is recorded that larvae of the potato-root eelworm penetrate the roots of black nightshade, but usually fail to develop. Many degenerate and die, and infected roots usually become necrosed. Tomato roots are more readily invaded than roots of black nightshade, and whereas necrosis is less evident, heavily infected roots tend to become swollen.

110. Fenwick, D. W., Peters, B. G. & Libbey, R. P. (1953). Effects of repeated field injections of D–D mixture against potato-root eelworm. *Ann. appl. Biol.*, **40**, 208.

Autumn injections of D–D mixture have been annually repeated for three years on a silt soil at Moulton (Holland, Lincolnshire) and a black fen soil at Prickwillow (Ely, Cambridgeshire), with different results. At Moulton there was an increased yield of tubers each time D–D was used, with no significant residual effects after the first year, and no marked long-term effect on the eelworm population. At Prickwillow D–D gave an increased yield in the first season only, with no positive residual effects on yield, and an apparent stimulating effect on the eelworm population. At Moulton in 1948 and 1950 (but *not* in 1949) the cost of the D–D treatment was heavily outweighed by the value of the resultant increase in crop. However, on the organic soil at Prickwillow D–D treatment was ineffective in 1949 and 1950, and the eelworm population, initially higher than at Moulton, remained at a level inducing failure of the potato crop.

111. Fenwick, D. W. & Reid, E. (1953). Population studies on the potato-root eelworm (*Heterodera rostochiensis* Woll.). *J. Helminth.*, **27**, 119.

This paper describes a series of pot experiments on population fluctuations of the potato-root eelworm. Data are presented on the degree of cyst emptying which occurs in the vicinity of a potato plant and on the build-up following

invasion. Rate of build-up following different initial levels of infestation is discussed; there is a negative correlation between the number of new cysts produced and their larval content.

112. Peters, B. G. (1953). Trial of ammoniacal gas liquor against potato-root eelworm. *Plant Pathology*, **2**, 65.

Ammoniacal gas liquor used in a pot test at about 1,800 gal./acre had negligible effect, both on the eelworms and on subsequently grown potatoes. At 9,000 gal./acre it killed 35 per cent of the eelworms and led to a greatly increased growth of tubers and roots; the latter supported a large eelworm population, which was finally 3·5 times that in the untreated controls.

113. Peters, B. G. (1953). Vertical migration of potato root eelworm. *J. Helminth.*, **27**, 107.

A simple apparatus is described in which was measured the vertical migration of *Heterodera rostochiensis* larvae in soil, in the presence of the host plant. The migrations upwards and downwards are comparable and limited to about 8 inches; they can be inhibited by water-logged soil and greatly reduced if the cysts (when near the surface) are exposed to insolation under glass.

114. Peters, B. G. (1953). Changes in potato-root eelworm population with time and depth. *J. Helminth.*, **27**, 113.

By growing potatoes in infested soil in sectional wooden boxes, changes in the population of potato-root eelworm have been observed at 5, 9, 13 and 19 weeks after planting, and at five 2-inch levels in the soil. Results show that most of the increase in population occurred during the last six weeks of the experiment and that the normal population changes proceed more slowly in the topmost level, leading to a lower final population there than at deeper levels.

Insecticides and Fungicides Department

General Papers

115. Potter, C. (1953). The control of crop pests. *Brit. med. J.*, no. 4819, 16th May 1953, p. 1093.

116. Potter, C. (Part author), (1952). Rothamsted experiments on field beans. Part 2. *J. Roy. agric. Soc.*, **113**, 70.

117. Potter, C. (1953). Fifty years of research at Long Ashton Research Station. *Chem. & Ind.*, 1168.

118. (Furlong, J. F.) & Potter, C. The pyrethrum industry of Kenya and Tanganyika with reference to research and analytical control. Colonial Products Advisory Bureau. 16th January 1953.

Research Papers

119. Connell, J. U. & Glynne Jones, G. D. (1953). Observations on the entry of dusts into the respiratory system of the adult worker honey bee, *Apis mellifera* L. *Bull. ent. Res.*, **44**, pt. 2, 291.

A description is given of the hair structures associated with the spiracles of the adult worker honeybee, *Apis mellifera* L.

The surface hairs around the spiracular orifices vary in size, density and arrangement and with the exception of those of the third, fifth and sixth abdominal spiracles appear to be capable of holding back particles greater than 30 microns.

When living bees were exposed to dust clouds of charcoal and cuprous cyanide, no particles were found in any internal part of the respiratory system beyond the spiracles, except in the case of the trachea of the first thoracic spiracle, which contained charcoal particles less than 5 microns.

The mechanism of tracheal ventilation was considered, and evidence accumulated to suggest that all spiracles could have an inspiratory function.

O

120. Lord, K. A. & Potter, C. (1953). Hydrolysis of esters by extracts of insects. *Nature, Lond.*, **172**, no. 4380, 679.

Extracts of most of the insect species examined hydrolyse phenyl acetate much more rapidly than acetyl choline. In some species it is difficult to detect the hydrolysis of acetyl choline owing to endogenous acid production. Some evidence is also available that this enzyme is inhibited in whole extracts of some species.

121. Mukerjea, T. D. (1953). The relationship between the stage of development and susceptibility to DDT and the pyrethrins of *Diataraxia oleracea* L., *Tenebrio molitor* L., and *Periplaneta americana* L. *Bull. ent. Res.*, **44**, pt. 1, 121.

A review of the literature is given which shows that changes in the susceptibility of insects to insecticides occur during development when the poison is applied as a fumigant, as a stomach poison and as a contact poison.

The basis of assessment of toxicity may be the concentration required to kill a given number of individuals, or the amount of poison required to kill unit weight of insect material. A mathematical method is given for transforming the results obtained in terms of concentration to kill a given number of individuals into weights of poison to kill unit weight of insect material. Rearing methods are outlined which enable batches of various stages of *Diataraxia oleracea* (L.) (tomato moth), *Tenebrio molitor* L. (meal worm) and *Periplaneta americana* (L.) (American cockroach) to be obtained at a known age and stage of development.

On the basis of the concentration of insecticide required to kill a given percentage of individuals, it is shown that great differences can occur in the resistance of different instars of one species, and considerable differences may occur within the instar. If the data for the larval and nymphal instars are considered on the basis of the weight of poison required to kill unit weight of insect material, differences still exist, but are much reduced.

The figures show that the range of variation of resistance during development may be very large, over 250 times in the case of DDT and *D. oleracea*, where the pupa is resistant. The maximum variation that was found within an instar was 16·6 times, where the resistance to pyrethrins of the one-day-old pupa of *T. molitor* was compared with that of the four-day-old pupa. The data show that the amount of variation in resistance that can occur varies with the test species and with the insecticide, furthermore, that the order of resistance of the developmental stages of any given species will differ with the insecticide, and that with any given insecticide the order will vary with the species.

It may be inferred from these data that any comparison between insecticides on one stage of development of one instar of one species will not necessarily hold true of any other stage of development of that species or of any other species.

Using data given in the literature and from some preliminary experiments on respiration rates, it was possible to deduce some correlation between metabolic rate and susceptibility, and changes in the permeability of the cuticle and chorion and susceptibility, but the evidence is unsatisfactory and the causes of the changes in susceptibility await further detailed investigation.

122. Salkeld, E. H. & Potter, C. (1953). The effect of the age and stage of development of insect eggs on their resistance to insecticides. *Bull. ent. Res.*, **44**, pt. 3, 527.

Laboratory spraying experiments were carried out with DDT, allethrin, the triethanolamine salt of 3 : 5-dinitrocresol (TDNOC) and HETP against eggs of different ages of *Diataraxia oleracea* (Lepidoptera) and with allethrin HETP and TDNOC against eggs of different ages of *Ephestia kühniella* (Lepidoptera) and *Dysdercus fasciatus* (Hemiptera) under controlled temperature and humidity conditions.

The shape of the resistance–age curves obtained varied with :

(1) the incubation temperature;
(2) the species of egg;
(3) the insecticide.

In eggs of *Diataraxia oleracea* very small differences in susceptibility with age were found with any of the insecticides at 75° F. and 60–70 per cent

relative humidity, but definite resistance–age curves were obtained with allethrin and TDNOC when the eggs tested had been incubated at 57° F. In this case the youngest (one-day) and the oldest eggs (fourteen-day) tested were the least resistant. DDT and HETP were tested only against the eggs of *D. oleracea* incubated at 75° F.; only small differences were found at this temperature. There were indications that the one-day-old eggs were the most resistant to these insecticides, but the results were barely significant.

The shape of the resistance–age curves for the two species of Lepidoptera tested under similar experimental conditions varied slightly but had a general similarity, but those for the Hemiptaran eggs were very different. This is ascribed to differences in chorion structure and process of development between these two species of eggs.

With any one species of egg, the shape of the resistance–age curve differed from one insecticide to another. Usually, however, the shapes of the curves obtained for allethrin and TDNOC were much the same. The different type of curve with HETP is ascribed to its ease of hydrolysis.

Details are given of the effect of the poison on embryonic development.

The appearance of eggs killed at an early stage in their development was characteristic for each insecticide. When development is inhibited by TDNOC the eggs turn brown and several small brown circles, which appear to be composed of yolk material, become closely applied to the chorion; with allethrin the yolk contents become dark in colour and quite liquid; with HETP the yolk contents are colourless and the chorion opaque.

From a study of the structure and composition of the protective envelopes in different ages of eggs of *L. oleracea* it has been found that membranes are formed by the ovum during development which may hinder the penetration of insecticides to the embryo. Maximal development of these membranes occurs near the middle of the incubation period. It was possible at this time to remove the embryo enclosed within these membranes from the chorion without apparent injury to the embryo itself. Details are given of the structure and development of the egg-shell of *D. oleracea*.

The results of dipping and washing experiments with eggs of *D. oleracea* indicated that the resistance–age relationships found was due to a difference in the ability of the insecticide to penetrate the shell layers and membranes rather than to differences in the inherent susceptibility of the embryos of different eggs.

The speed of penetration of TDNOC into eggs of *D. oleracea* as determined in respiration experiments was very rapid, irrespective of the age of the egg. The poisoned eggs showed a marked initial rise in oxygen consumption, the extent of which depended upon the age of the egg, a greater increase being noticed in the one- to two- and five-day eggs than in the three- and four-day eggs. Although the metabolism of these eggs was affected, the embryos continued their development apparently normally until reaching one of the two critical stages. It is suggested that the number of embryos that succeed in passing the critical stages and in hatching depends upon the extent of the initial metabolic disturbance caused by the poison, which in turn depends upon the amount of poison reaching the embryonic material. The extent of the metabolic disturbance is an index of the amount of poison entering the egg-shell, and therefore of ultimate toxicity. The shape of the respiration curves indicates that the majority of the poison reaches the embryo either soon after application or towards the end of the incubation period, when the serosal membrane and fluids are resorbed. Thus differences in resistance that occur in the eggs of different ages are due to changes in the permeability of the egg-shell which allow more or less poison to reach the embryo.

A close correlation appears to exist between the age of eggs which shows maximum resistance to the insecticide and the age of eggs in which the embryonic membranes are present at their maximum stage of development.

123. Tattersfield, F., Kerridge, J. R. & Taylor, J. (1953). The effect of repeated spraying of insects in increasing their resistance to insecticides. I. Development of resistance to DDT in a strain of *Drosophila melanogaster* Meig. *Ann. appl. Biol.*, **40**, no. 3, 498.

Successive spraying with DDT suspensions of the adults of a wild colony of *Drosophila melanogaster* and the progeny of survivors enhanced the resistance of that insecticide.

The rate at which resistance increased depended on: (1) the relative proportion of resistant to susceptible individuals; or (2) the intensity of selection as measured by the concentration of DDT and the proportion killed; or on both. The resistance of the populations of the insects fluctuated considerably whether subjected to successive sprayings or not, and in one sprayed series there was some indication of a rhythm, with peaks of susceptibility occurring at regular intervals.

Enhanced resistance may show a change of slope in the probit log concentration regression line, leading to different relative values at different levels of mortality, or by a parallel shift of the regression line. The former appears to be a preliminary stage of selection, and indicates a change in the frequency distribution within a population.

Increasing the concentration of DDT, slowly or rapidly, may have enhanced resistance at an increased rate, but the series sprayed with the lower initial concentration reached finally the same end point, as judged by the values of log L.C. 50.

During the course of these experiments the insects developed sensitivity to carbon dioxide (used in anaesthesis). Its bearing on our work is considered in Part II.

124. Tattersfield, F. & Kerridge, J. R. (1953). The effect of repeated spraying of insects in increasing their resistance to insecticides. II. The effect of carbon-dioxide sensitivity on the toxicity of DDT within a strain of *Drosophila melanogaster*. *Ann. appl. Biol.*, 40, no. 2, 523.

During the selection of a stock of *Drosophila melanogaster* for resistance to DDT, in which carbon dioxide was used for purposes of anaesthesis, a sensitivity to this gas developed. The phenomena closely paralleled those shown by the CO_2-sensitive ebony stock isolated by L'Héritier and his co-workers. An experimental analysis of its effect upon DDT sensitivity was made. It was found that a stock selected for CO_2 resistance gave the same probit regression line as the original stock. A CO_2-sensitive stock, whether anaesthetized with nitrogen or carbon dioxide, gave the same regression line at a temperature of 25° C. at which CO_2 sensitivity disappeared, or at 15° C. if adjustment to the proportion of deaths in the control was made. The effect of CO_2 was therefore to limit the population from which selection is made for DDT resistance, rather than to alter the distribution of DDT resistance within the stock.

125. Turner, N. & Bliss, C. I. (1953). Tests of synergism between nicotine and the pyrethrins. *Ann. appl. Biol.*, **40**, no. 1, 79.

Synergism between nicotine and pyrethrum applied by injection to adult *Oncopeltus fasciatus* Dal. has been reported by Turner (1951).

When these insecticides were applied alone and as a mixture to adult *Tribolium castaneum* Hbst., using a dipping technique, the data indicated that independent joint action occurred. Similar action could be eliminated because the two insecticides had varying relative potency.

Since the effect of the pyrethrins has been short-lived in some insects, it was postulated that the absence of synergism might be caused by failure of the nicotine to reach a site of action while the pyrethrins were still acting.

Application of nicotine, followed later by treatment with pyrethrins, gave evidence of synergism. A test in which the interval between treatments was varied from $\frac{3}{4}$ to 6 hours showed that toxicity was greatest with the shortest interval between applications, and evidence of synergism had practically disappeared after 6 hours. The maximum amount of synergism observed was about twofold.

126. Ward, J. (1953). Separation of the " Pyrethrins " by displacement chromatography. *Chem. & Ind.*, no. 24, 586–587.

The technique of displacement chromatography has been used to isolate pyrethrin I, pyrethrin II, cinerin I and cinerin II from a purified extract of pyrethrum flowers. Adsorbent alumina was contained in a glass column which gradually tapered to a small bore at the bottom. The extract, dissolved in *n*-hexane, was allowed to percolate into the top of the column, and the adsorbed " pyrethrins " were then eluted with a solution of stearic acid in

n-hexane. The pyrethrin content of the eluate was followed by measuring its ultra-violet absorption. The materials emerged in the order: cinerin I, pyrethrin I, cinerin II, pyrethrin II. The molecular extinction coefficients and the biological activities of the constituents were measured.

Entomology Department

127. Barnes, H. F. (1953). Outlines of insect phenology. *Trans. 9th Int. Congr. Entom.*, **2**, 163.

Definition of "phenology"; landmarks in the origin and development of the science; and phenology as exemplified in the Cecidomyidae or gall midges.

128. Barnes, H. F. (1953). The Wheat Blossom Midges. *New Biol.*, **14**, 82.

An essay based on twenty-five years' investigation of these gall midges as they occur on Broadbalk.

129. Barnes, H. F. (1953). The absence of slugs in a garden and an experiment in re-stocking. *Proc. zool. Soc. Lond.*, **123**, 49.

The introduction and subsequent observation of 1,000 Grey Field slugs in a garden where they were absent has shown that most probably this species had died out during some previous dry spell owing to the failure of the almost humus-free soil to retain moisture.

130. Barnes, H. F. (1953). The biological approach to the species problem in gall midges (Dipt., Cecidomyidae). *Ann. ent. fenn.*, **19**, 2.

An account of the use that has been made of the biological approach during the past quarter of a century and an indication of some immediate needs.

131. Barnes, H. F. (1953). Description of the new gall midge found by M. R. Pussard on Lavender, together with notes on the damage caused by some other species. *Bull. Soc. ent. Fr.*, **58**, 125.

132. Barnes, H. F. (1953). The Shasta Daisy Midge and other insects in flowers of *Chrysanthemum* species. *Plant Pathology*, **2**, 52.

Preliminary information on the biology, the range of oviposition on *Chrysanthemum* species and the distribution in the British Isles of the Shasta Daisy Midge (*Contarinia chrysanthemi*), together with notes on the distribution of two other primary gall midge species, as well as other gall midges, flies, weevils, moths and hymenoptera.

133. Barnes, H. F. & (Palmer, Ray) (1953). Bedfordshire plant galls. Preliminary list. Part 1. Diptera. *Bedfordshire Naturalist*, **7**, 21.

134. (Buxton, P. A.) & Barnes, H. F. (1953). British Diptera associated with fungi. 1. Gall midges (Cecidomyidae) reared from the larger fungi. *Proc. R. ent. Soc. Lond., B*, **22** (11/12), 195.

Includes the description of a new species reared from *Auricularia auricala-judae*.

134*a*. Johnson, C. G. (1952). The role of population level, flight periodicity and climate in the dispersal of aphids. *Trans. 9th Int. Cong. Entom.* **1**, 429.

135. Johnson, B. (1953). Flight muscle autolysis and reproduction in aphids. *Nature, Lond.*, **172**, 813.

135*a*. JOHNSON, B. (1953). The injurious effects of the hooked epidermal hairs of French Beans (*Phaseolus vulgaris* L.) on *Aphis craccivora* Koch. *Bull. ent. Res.* **44**, 779.

136. JOHNSON, C. G. (1954). Aphid migration in relation to weather. *Biol. Rev.*, **29**, 1.

137. (TAYLOR, C. E.) & JOHNSON, C. G. (1954). Wind direction and the infestation of bean fields by *Aphis fabae* Scop. (In the press.)

137*a*. LONG, D. B. (1953). Effects of population density on larvae of *Lepidoptera*. *Trans. R. ent. Soc. Lond.*, **104**, 543.

A study has been made in some detail of effects on the morphology, physiology and behaviour of larvæ. In some species crowded cultures were darker in colour than their solitary controls and the factors involved have been considered. Crowding increased the rate of development and decreased the number of instars. This was accompanied by a more simultaneous development which in a multi-voltine species could under favourable conditions lead to a population build-up. In general the effects were shown to be comparable with the "phases" of locusts.

138. SOUTHWOOD, T. R. E. (1953). The morphology and taxonomy of the genus *Orthotylus* Fieber (Hem., Miridae), with special reference to the British species. *Trans. R. ent. Soc. Lond.*, **104**, 415.

An account of the general morphology of the genus and a reassessment of the taxonomic value of various characters. The structure of the genus, which is divided into four sub-genera, two of which are new, is discussed. A key is given to the eighteen British species.

139. SOUTHWOOD, T. R. E. (1953). Interspecific copulation between *Nabis ferus* (L.) and *N. rugosus* (L.) (Hem., Nabidae). *Ent. mon. Mag.*, **89**, 294.

A brief account of an observation which suggests the existence of a mechanical barrier to pairing in these two sympatric species.

140. STOKES, B. M. (1953). The host plant range of the Swede Midge (*Contarinia nasturtii* Kieffer) with special reference to types of plant damage. *Tijdschr. PlZiek.*, **59**, 82.

141. STOKES, B. M. (1953). Biological investigations into the validity of *Contarinia* species living on the Cruciferae, with special reference to the Swede Midge, *Contarinia nasturtii* (Kieffer). *Ann. appl. Biol.*, **40** (4), 726.

142. WILLIAMS, C. B. (1953). Comment on a query about a missing value in an insect bait trap experiment. *Biometrics*, **9** (3), 425.

Showing that the working out of a missing value in a trapping experiment on insects may give unreliable results if the catches are used on an arithmetic scale. The use of a geometric (logarithmic) scale is believed to give more reliable results.

143. WILLIAMS, C. B. (1954). The statistical outlook in relation to ecology. *J. Ecol.*, **42** (1), 1.

Presidential address to the British Ecological Society dealing with the effect of the mathematical and statistical outlook on various ecological problems, including the layout and interpretation of experiments, and particularly studies made at Rothamsted on the relative abundance of species; on the numbers of species in different genera; on the measurement of diversity; and on intra-generic competition in animals and plants.

Bee Department

Books

144. BUTLER, C. G. (1954). *The world of the honeybee.* (New Naturalist Series). London: Collins.

145. RIBBANDS, C. R. (1953). *The behaviour and social life of honeybees.* London: Bee Research Association Ltd.

General Papers

146. Butler, C. G. (1953). The present status of beekeeping in Ceylon and possibilities for its future development. *Brit. agric. Bull.*, **6** (no. 26), 125.

147. Butler, C. G. (1953). A report on the results of an investigation into the possibilities of beekeeping in Ceylon, together with some suggestions for the future development of beekeeping in the Island. *Sessional Paper, Govt. of Ceylon.*

Research Papers

148. Bailey, L. (1953). The effect of fumagillin upon *Nosema apis* (Zander). *Nature, Lond.*, 171, 212.

The curative effect of fumagillin upon an established infection within individual bees is described. The drug acts upon the developing intracellular stage of the parasite, but relapses occur even after continuous treatment for seventeen days.

149. Bailey, L. (1953). The treatment of Nosema disease with fumagillin. *Bee World*, **34**, 136.

The results of autumn treatment of infected colonies with fumagillin are given. The preventive effect of this treatment upon the resurgence of the disease during the following spring was striking. However, a low level of infection became apparent in treated colonies in late spring. It is considered to have arisen from the old comb, which still contained viable spores from the previous year.

150. Bailey, L. (1953). The transmission of Nosema disease. *Bee World*, **34**, 171.

The carrying over of the disease from one year to the next by spores upon comb has been demonstrated. The transference of colonies from old combs to new comb foundation during early summer has been shown to be effective in breaking the cycle of infection, as the transmission of this disease from infected to healthy bees virtually ceases during the flying season.

151. Ribbands, C. R. & Speirs, Nancy (1953). The adaptability of the homecoming honeybee. *Brit. J. anim. Behav.*, **1**, 59.

Groups of foraging bees of known ages were marked individually and introduced to a colony of bees. One to five days later the breedchamber housing this colony was turned through 90° and changed in height. Two days later it was turned through a further 90° and its height was changed again. The marked bees reorientated quickly and completely in these experiments, and their age had no effect upon their adaptability. Colony odour facilitated reorientation.

152. Ryle, M. (1954). The influence of nitrate, phosphate and potash on the secretion of nectar. Part I. *J. agric. Sci.* (In the press.)

153. Ryle, M. (1954). The influence of nitrate, phosphate and potash on the secretion of nectar. Part II. *J. agric. Sci.* (In the press.)

These two papers describe the results of work on the effect of fertilizer treatment on nectar secretion in mustard, buckwheat, apple and red clover. It has been shown that in the case of apple-trees the mean quantity of sugar produced per flower can be significantly increased by extra potash. In experiments with the other plants mentioned it was found that any treatment which checked growth at flowering time, apart from a shortage of potash, increased the yield of nectar.

154. Wykes, Gwenyth, R. (1953). The sugar content of nectars. *Biochem. J.*, **53**, 294.

The sugars present in nectar secreted by twelve species of plants were separated on paper chromatograms, and quantitative determinations were made of the glucose and fructose present. It was found that the proportions of glucose and fructose varied greatly in nectar from the different species, but, for any one species, the proportions of these sugars appeared to remain relatively constant.

Statistics Department

Books

155. Yates, F. (1953). *Sampling methods for censuses and surveys.* 2nd Edition. London: Griffin.

Two new chapters have been added. These amplify certain aspects not fully dealt with in the first edition and contain accounts of various recent developments. Some space is also devoted to problems arising in the analysis of investigational surveys.

(Translations of the 1st Edition into French (1951) and Japanese (1953) have also been published.)

156. Fisher, R. A. & Yates, F. (1953). *Statistical tables for biological, agricultural and medical research.* 4th Edition. Edinburgh: Oliver & Boyd.

New material included in the fourth Edition is: a table providing a test for the existence of a periodic component; a table of segmental functions which serve to specify the frequencies of non-recombinant and recombinant gametes in terms of the metrical positions of the centromere, a series of markers and the terminus of the chromosome arm; random permutations of ten and twenty numbers for use in the construction of experimental arrangements; an additional table of the normal integral with the deviation from the mean of the distribution as argument. The section of the introduction on dosage mortality tests involving a natural death-rate has also been re-written.

Research Papers

157. Boyd, D. A. & Lessells, W. J. (1954). The effect of seed-rate on the yield of potatoes. *J. agric. Sci.* (In the press.)

This paper examines the relation between seed-rate and yield of maincrop potatoes, using data from experiments reported in the literature. Optimum seed-rates are presented for a range of prices of seed and produce, and these are compared with estimates, derived from the Survey of Maincrop Potatoes and the Survey of Fertilizer Practice, of the actual amounts planted by growers in different parts of the country.

Provided the optimum seed-rate is attained, the precise combination of seed size and spacing distance appears to be of minor importance. The optimum rate of planting of certified seed is estimated to be 16–17 cwt./acre in the main potato-growing areas of the country, while the normal planting rate in these districts is over 1 ton/acre. The failure to plant at the optimum seed-rate results in an estimated loss of 20–25*s.*/acre. For once-grown seed the optimum seed rate is at least 1 ton/acre, whilst the average weight of seed planted is only about 17 cwt./acre, resulting in a loss per acre of 10–15*s.*

The explanation of the discrepancy between experiment and practice appears to be that a grower usually maintains the same spacing between sets regardless of their size; certified seed tends to be larger in size than does once-grown seed.

158. Boyd, D. A. & Lessells, W. J. (1954). Influence of fertility levels on grassland output. I. Review of fertilizer experiments on grassland in relation to current fertilizer usage. *Brit. J. Grassl. Soc.* (In the press.)

The paper sets out to summarize very briefly the results of experiments carried out on the effect of fertilizers applied to grassland. The yield of starch

equivalent from nitrogen applied to dried grass, silage and hay varies between 10 and 15 per cwt. N according to the quality of the product. Responses of hay to phosphate and potash are also quoted. For grazed land, which amounts to over two-thirds of the total grassland acreage each year, very little experimental data on fertilizer responses is available; what there is suggests that moderate quantities can be applied without unduly affecting the legumes in the sward, when they give as good a return as in the experiments on conserved grass, but that the successful use of larger quantities demands a high standard of grazing management.

Results from the Survey of Fertilizer Practice show that whilst the amount of nitrogen used in practice rose considerably from the very low level during and before the war, it has remained practically unchanged since 1950, although there was evidence of a slight upward trend in 1953. More than half the leys and three-quarters of the permanent grass received no nitrogen in 1952–53. There are considerable variations within the country; intensive dairying districts like West Cheshire and the Fylde district of Lancashire are using about 0·25 cwt. N per acre on temporary grass and 0·1 cwt. N per acre on permanent grass, whereas in many less-intensive rearing and feeding districts less than one-quarter of these amounts is being used.

A simple calculation shows that if the acreage of grassland dressed with nitrogen could be doubled the gross return for expenditure of about 70,000 tons N would be about 0·8 m. tons starch equivalent, giving a net return of something like £10 m. Such an increase could not, however, be attained without at the same time effecting an improvement in management so that the extra feed produced was actually utilized.

For phosphate and potash there is little clear evidence of how much is required, except for permanent meadows and leys cut for hay, silage, etc. Whilst there are still individual farms and districts where phosphate deficiencies have not been overcome, the phosphate status of most of our grassland has improved substantially in recent years, and the average consumption at about 0·2 cwt. P_2O_5 per acre does not appear unduly low. It is, however, much less than the amount used by many successful graziers, and here again there is a great need for extensive experimental work.

159. Church, B. M., (Jacob, F. H. & Thompson, H. V.) (1953). Surveys of rabbit damage to wheat in England and Wales, 1950–52. *Plant Pathology*, **2**, 107.

In 1950 a pilot survey was carried out in Kent to estimate rabbit damage on spring wheat by comparing yields on protected and unprotected plots. The methods used in this survey, and in the 1952 survey of winter wheat in England and Wales, are described. The survey results show that the differences between the average yields on protected and unprotected plots must be almost entirely due to rabbit damage. The estimated average loss of winter wheat throughout the country in 1952 due to rabbit grazing was 1½ cwt. grain per acre.

160. (Constable, D. H.) & Hodnett, G. E. (1953). The manuring of *Hevea brasiliensis* at Dartonfield, Ceylon. *Emp. J. exp. Agric.*, **21**, 131.

The data on girth of the trees and yield of rubber obtained during the first thirteen years of a fertilizer trial on *Hevea brasiliensis* at Dartonfield have been analysed. With both girth and yield the principal response was to phosphate. The results of this experiment did not indicate any appreciable interactions.

161. Dyke, G. V. & Avis, P. R. D. (1953). A survey of maincrop potatoes, 1948–1950. I. Estimates of yield. *J. agric. Sci.*, **43**, 450.

A survey of maincrop potatoes was carried out by members of the National Agricultural Advisory Service in 1948, 1949 and 1950 in collaboration with the Statistics Department. Potato-growing farms in forty counties were grouped according to potato acreage, and random selections were made with differing sampling fractions. Each farm was visited several times, and many particulars obtained; the present paper deals only with estimates of yield.

These were based on small samples dug by hand from specified locations in (at most) two fields per farm.

The standard error of the mean (based on about 1,000 sampled fields) was about 0·2 tons/acre (2 per cent). The sample estimates were compared with yields calculated from the total weights of produce per field wherever these were obtainable. This showed good agreement in 1948 and 1949, but an excess of the sample estimates of 0·9 tons/acre in 1950, possibly because a late infection of blight reduced the final yield.

The official estimates issued by the Ministry of Agriculture are shown to be less than the sample estimates by about 1¾ tons/acre in each year. Underestimation seems to arise almost entirely from the counties which in a particular year have high yields, yields of 7 tons and under being estimated without serious bias by the official Crop Reporters.

162. Healy, M. J. R. (1953). A method for comparing fly-repellant sprays. *Biometrics*, **9**, 290.

In a standard method for comparing two fly-repellant sprays, batches of mice are treated with the two materials under test and are subsequently exposed to attack by *stomoxys* flies. An untreated batch is included for purposes of comparison, and it is found that the attack rate in the controls varies considerably from one batch to another. If p_0, p_1, p_2 are the observed mean attack rates in the controls and the two sets of treated mice on any one occasion, it is assumed that only a proportion p_0 of the flies were liable to attack in the treated batches, so that p_1/p_0, p_2/p_0 are estimates of the attack rates in the treated mice if all the flies were liable to attack. Assuming these "true" attack rates to be essentially constant, a method is given for estimating them from observed data and for making statistical comparisons.

163. Healy, M. J. R. (1953). Principles of biological assay. (In: *Modern methods of plant analysis*, edited by K. Paech and M. V. Tracey.)

An outline is given of the commoner statistical techniques used in biological assay. The subjects covered include direct assays, parallel line and slope-ratio assays with a quantitative response and probit assays. There are discussions of the planning of assays and of suitable experimental designs, and worked examples of the recommended techniques.

164. Healy, M. J. R. & Dyke, G. V. (1954). A Hollerith technique for solving normal equations. *J. Amer. statist. Ass.* (In the press.)

In the critical analysis of survey data it is often necessary to fit constants to observed data by the method of least squares. The resulting simultaneous equations are most readily solved by a process of successive approximation, and a technique is given for carrying out this process on a Hollerith sorter and tabulator. In data arising from a survey of maincrop potatoes involving some thirty equations, the method was about five times as fast as hand computation.

165. Leech, F. B. & (Bailey, G. L.) (1953). The effect on the health of lactating cows of treatment with galactopoietic doses of thyroxine or iodinated casein. *J. agric. Sci.*, **43**, 236.

The effect on cow health of galactopoietic stimulation with thyroactive materials was determined from a statistical study of the results of a large field experiment involving 2,000 cows over a three-year period. The same experimental procedure was followed on thirty-seven farms scattered over England, Scotland and Wales. This procedure was planned to ensure that half the cows in each herd would receive a course of treatment with iodinated casein or thyroxine, and that the other half would constitute a suitable set of controls. Cows that remained in the herds received second and third treatments in successive lactations. The galactopoietic stimulation was started at a fixed interval after calving, irrespective of the season of the year.

The use of the thyroactive materials in successive lactations did not have any serious adverse effects on the health of cows. The effect on productivity was less than had been expected, since the increase in milk yield resulting

during the period of hormonal treatment was often largely or completely negatived by a shortening of the lactation period. The incidence of disease was somewhat greater in the treated than the control group, the principal contribution to this difference being from the diseases described as digestive disorders. There were some other differences of lesser significance. The rate of disposal of treated and control groups was almost identical. There were no adverse effects on the reproductive life of treated cows; factors studied were the efficiency of coitus, interval between parturitions, length of gestation and incidence of abnormalities at parturition.

During the period of treatment, there was a marked response in daily milk yield, but the fat content of the milk was not raised. L-Thyroxine sodium replaced iodinated casein on twenty-six farms during the second and third years. There was no significant difference in the milk-yield responses resulting from the two drugs. Cows readily ate cubed feeding-stuffs containing thyroxine, but frequently did not relish similar cubes fortified with iodinated casein.

166. (Paterson, A. B.) & Leech, F. B. (1954). Factors affecting the intradermal tuberculin reaction on the guinea-pig. *Amer. Rev. Tuberc.* (In the press.)

Differences in the dose-response curves of PPD and OT tuberculins were demonstrated on guinea-pigs sensitized with dead organisms in oil; such differences can be measured only in large-scale assays. Similar results were obtained when the same experiment, using a fresh randomization scheme, was repeated after an interval of three months, on the same set of sensitized guinea-pigs.

Multiple tuberculin injections in the sensitized guinea-pig depressed the response to the individual injection. The depression is probably related to the degree of systematic response, and is not a local influence of one tuberculin reaction on an adjacent one.

167. Patterson, H. D. (1954). The errors of lattice sampling. *J. R. statist. Soc. B.* (In the press.)

Samples can be selected from a $p \times p \times p \times \ldots$ classification with one unit in each sub-class in such a way that they include equal numbers of units from each main class or from each combination of two, three or more main classes in different classifications. Such samples can be named *lattice samples*. The paper provides a discussion of the errors of lattice samples.

Methods for (*a*) determining the errors of lattice sampling from the population data and (*b*) estimating the errors (if this is possible) from the actual sample data, are described in detail for the cases of the $p \times p$ classification and the $p \times p \times p$ classification. The results are extended to the general case of p^n classification. In addition, examples of lattice sampling from $p \times p \times q$ classifications and lattice sampling at a single stage of multi-stage sampling are briefly considered.

168. Yates, F. (1954). The analysis of experiments containing different crop rotations. *Biometrics.* (In the press.)

The problems arising in the analysis of experiments containing different crop rotations are investigated. When the design of the experiment is such that each block contains plots which sometimes carry a given crop but do not all carry the crop in the same set of years the year-block totals will not be orthogonal with the plot totals. In most such cases the fitting of constants must be resorted to in order to obtain separate estimates of plot error and plot × year error which are free of year × block interactions. The method is illustrated by application to a rice-pasture experiment containing rotations of different lengths and with different proportions of rice to pasture.

169. Yates, F. (1953). The wider aspects of statistics. (Address given at the inauguration of the Sixth Annual Meeting of the Indian Society of Agricultural Statistics.) *J. Ind. Soc. agric. Stat.* (In the press.)

The need for statisticians to play their part in the planning of experimental programmes, the critical appraisal of their results as a whole and the

application of these results to the improvement of agricultural production is emphasized.

170. YATES, F., (FINNEY, D. J. & PANSE, V. G.) (1953). The use of fertilizers on food grains. *I.C.A.R. Res. Series, No.* 1.

All readily available facts on responses of Indian food grains to sulphate of ammonia and superphosphate are summarized. It was found that the nitrogen responses are in the main very consistent, 2·5 maunds of grain per acre from 20 lb. N per acre being a reasonably representative figure for all cereals. For phosphate, responses are smaller and more variable. One series of experiments on cultivators' fields consistently shows appreciable responses to potash for paddy and maize, suggesting that the usual statements about the adequacy of potash in most Indian soils need re-examination.

The economics of fertilizer application is outlined. The conclusion is reached that, at present prices, 20 lb. N per acre as sulphate of ammonia to food grains will be definitely profitable on most soils, and that an equal dressing of P_2O_5 will be equally good if restricted to the more responsive soils. From the point of view of the national balance of payments, such manuring is relatively even more advantageous than it is to individual cultivators: a large-scale programme of fertilizer use, if necessary temporarily aided by imports of fertilizer, could go far towards removing India's food deficit.

171. YATES, F. & GRUNDY, P. M. (1953). Selection without replacement from within strata with probability proportional to size. *J. R. statist. Soc. B.*, **15**, 253.

In selection with probability proportional to size x from within strata without replacement, the usual method of selection gives rise to bias in the estimate of the total of a variate y derived by weighting the units by weights proportional to $1/x$. By means of numerical examples it is shown that the amount of this bias is usually quite trivial. If, however, unbiased estimates are required, the true total probabilities of selection of the different units can be easily calculated for samples of 2, and with considerably more labour for samples of 3.

The bias in the ordinary formula for the estimation of error is also investigated, and the formula is shown to be reasonably accurate. An unbiased estimator put forward by Horvitz and Thompson in 1952 is shown to be very inefficient, and a new unbiased estimator is given.

A method for revising the size measures so that with the usual method of selection the true total probabilities of selection are proportional to the original size measures is given for samples of 2. Horvitz and Thompson's solution of this problem does not appear to give satisfactory approximations in the cases met with in practice.

The selection of successive members of a sample with arbitrary sets of probabilities chosen solely so that the total probabilities shall be proportional to the original size measures, which has been advocated in various quarters, is criticized.

REVIEWS

172. HEALY, M. J. R. (1953). "The Statistics of Bioassay," by C. I. Bliss; "Statistical Method in Biological Assay," by D. J. Finney; "Probit Analysis," by D. J. Finney. *Biometrika*, **40**, 473.

173. HEALY, M. J. R. (1953). "The Design and Analysis of Experiment," by M. H. Quenouille. *J. R. statist. Soc. A*, **116**, 453.

174. PATTERSON, H. D. (1953). "Field Experimentation with Fruit Trees and Other Perennial Plants," by S. C. Pearce. *Nature, Lond.*, **172**, 221.

175. YATES, F. (1953). "Cambridge Elementary Statistical Tables," by D. V. Lindley and J. C. P. Miller. *Nature, Lond.*

Reports

176. (Edwards, D. A. W., Hammond, W. H.) Healy, M. J. R. (& Tanner, J. M.). (1953). Design of skinfold calipers—preliminary report to the Medical Research Council Committee on Growth and Form.

177. Hodnett, G. E. (1953). Statistical methods for sample surveys. African Training Centre for Agricultural Statistics, F.A.O. ATCAS/C.3.

178. Hodnett, G. E. (1953). The responses of sugar-cane to fertilizers in British Guiana, Mauritius, Barbados and Antigua. Reports to the Colonial Office.

General Publications

179. Boalch, D. H. (1953). *The manor of Rothamsted.* Harpenden : Rothamsted Experimental Station.

180. (Gardner, H. W.) & Garner, H. V. (1953). *The use of lime in British agriculture.* London : E. & F. Spon Ltd.

181. Garner, H. V. (1952). More about salt. *Brit. Sug. Beet Rev.*, **21**, 75.

182. Garner, H. V. (1953). Manuring of sugar beet. Chap. VIII of *Min. Agric. Bull.*, **153**, 30.

183. Ogg, Sir W. G. (1953). Organic manures and fertilizers. Contribution to discussion on organic manures and fertilizers and the production and composition of food for man and animals. *Proc. R. Soc. Med.*, **46**, (9), 791, Sept., 1953.

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*1939 Nicol, Hugh. *Microbes by the million.* Harmondsworth: Penguin Books Ltd.

*1939 Russell, Sir. E. J. *Artificial fertilizers in modern agriculture.* Ministry of Agriculture and Fisheries Bulletin no. 28. 3rd edition. London: H.M. Stationery Office, 1939.

*1939 Russell, Sir E. J. *Report on the work of the Imperial Council of Agricultural Research in applying science to crop production in India.* Reprinted. Simla: Government of India Press.

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1940 NICOL, Hugh. *Plant growth substances.* 2nd edition. London : Leonard Hill, 3/6.
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1945 BUTLER, C. G. *Bee-keeping.* Min. Agric. Bulletin no. 9, [7th edition]. London : H.M. Stationery Office, 9*d*.
1946 RUSSELL, Sir E. J. *British agricultural research : Rothamsted.* Revised edition. London : published for the British Council by Longmans, Green & Co., 1/6.—A Spanish translation (new impression, 1947, 1/-) and a Portuguese translation (1942, 1/-) are available from the same publishers.
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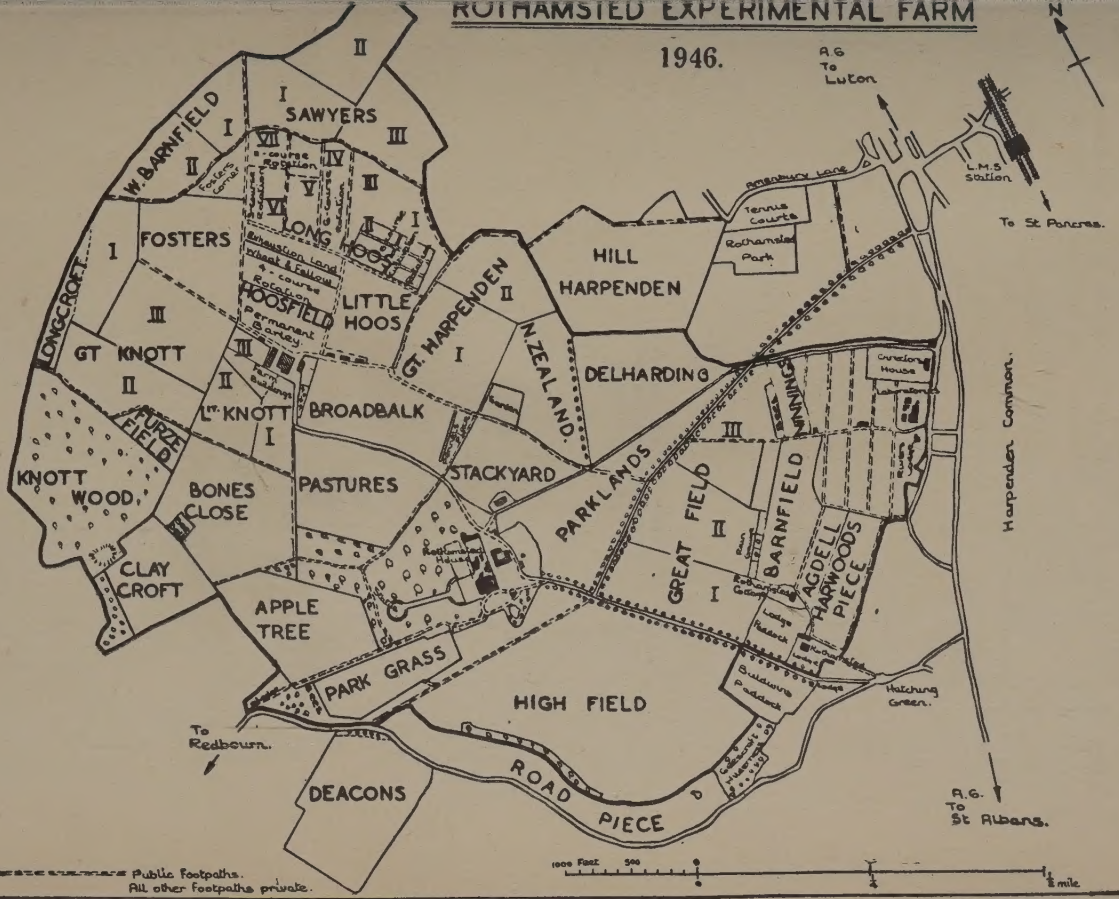

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